Assessment of the potential use of the groundwater resources in the area south of Mount Gambier

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by

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**PRIMARY INDUSTRIES AND RESOURCES
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ASSESSMENT OF THE POTENTIAL USE OF THE GROUNDWATER RESOURCES IN THE AREA SOUTH OF MOUNT GAMBIER

Fred Stadter and Wei Yan

Numerical modelling of the hydrogeology in the area south of Mount Gambier was used to examine the potential of increasing the Permissible Annual Volumes of extraction for the unconfined aquifer beyond the levels of assessed vertical recharge to the aquifer.

A three layered groundwater model was constructed and calibrated against existing long term groundwater level records and monitored coastal spring discharges.

Six different extraction scenarios were modelled using varying head conditions for the unconfined aquifer along the northern boundary of the model.

Results from the modelling indicated that:
- **the drawdowns in the unconfined aquifer increased with higher extraction rates, with possible unacceptable impacts to existing groundwater users**
- **the discharges from the coastal springs decreased significantly with the higher extraction rates, with potential adverse impacts on the terrestrial and marine environments in these areas**
- **there was a reduced discharge from the unconfined aquifer to the sea for the higher extraction rates with the potential risk of a raised salt-water interface in areas close to the coast, which could adversely effect both groundwater users and the established environment in these areas**
- **there was an increased groundwater inflow for the unconfined aquifer across the northern boundary of the model area for the higher extraction rates, which would exacerbate the longer term decline in water levels being observed in the general Mount Gambier area.**

It is recommended that the Permissible Annual Volumes of extraction for the unconfined aquifer be retained and not be increased, and that there be increased monitoring of groundwater levels and quality to assess the impacts of current levels of extraction.

It is also recommended that investigations be undertaken to assess the environmental significance of the discharges from the coastal springs, to determine the position of the salt-water interface within the unconfined aquifer and to determine the dependence of the coastal wetland environments on the groundwater level elevations in the unconfined aquifer.

INTRODUCTION

The South East of South Australia is almost totally reliant on its extensive groundwater resources which predominantly occur in two regional aquifer systems – an upper unconfined aquifer and a deeper confined aquifer.

Management of these groundwater resources has been enacted at different times in the past through the prescription of various defined areas under existing water resource legislation, with the most recent area to be prescribed being the Lacepede–Kongorong Prescribed Wells Area. Within each Prescribed Wells Area, all groundwater use except stock and domestic supplies are licensed according to various management policies.

The groundwater resources of the unconfined aquifer are generally managed according to the vertical recharge received by the aquifer from the infiltration of rainfall, such that the total allocations in any specific management area do not exceed the vertical recharge.

Over the last few years, particularly following the prescription of the Lacepede-Kongorong Prescribed Wells Area in 1997, the potential to use some of the lateral throughflow of groundwater in the unconfined aquifer in addition to the vertical recharge has been raised as a management issue for areas close to the coast. The area south of Mount Gambier has been especially identified, given the large spring discharges at the coast from the unconfined aquifer.

An assessment of the potential use of the groundwater resources from the unconfined aquifer in the area south of Mount Gambier has been undertaken by the Department for Water Resources. The study was partially funded by the South East Catchment Water Management Board to provide technical input for the water allocation plans being developed for the Comaum – Caroline and Lacepede – Kongorong Prescribed Wells Areas.

This assessment was made by developing a groundwater model for the area shown in Figure 1 and examining the predicted hydraulic impacts of various levels of use from the unconfined aquifer.

The study also includes:

- options for possible management areas should the model indicate that it is possible to use some of the lateral throughflow of groundwater in the unconfined aquifer.
- an appraisal of the current groundwater monitoring network and whether it should be supplemented should there be potential to use some of the lateral throughflow of groundwater in the unconfined aquifer.
- a determination of the groundwater monitoring criteria for such additional groundwater use and an estimate of the cost for this monitoring.

This report presents the results and conclusions of the study.

LAND USE

There are a number of different land uses in the study area. Softwood afforestation is prevalent and extensive areas have been planted, particularly in the eastern part of the study area. Traditional livestock grazing of sheep and cattle is also widespread throughout the area.

Over the last few years, there has been a marked increase in irrigation activity throughout the area. The majority of this irrigation has been established for dairy enterprises, with improved pastures being the main irrigated crop.

In the northern part of the study area, near Mount Gambier, other irrigated crops such as various vegetables, small seeds and fodder are grown.

Almost all the irrigation, stock and domestic water use is reliant on the groundwater resources of the unconfined aquifer. There are currently only three known water supply wells that source groundwater from the confined aquifer; two privately owned wells and a well owned by SA Water to provide a reticulated supply to the Port MacDonnell township.

HYDROGEOLOGY OF THE MODEL AREA

The model area as shown in Figure 1 forms part of the Gambier Embayment of the Otway Basin. The sedimentary sequence was deposited intermittently from Jurassic through to Recent times. The main hydrogeological units are the Tertiary Gambier Limestone unconfined aquifer and the Dilwyn Formation confined aquifer. The relationship of these aquifers is shown in a north to south hydrogeological cross-section shown in Figure 2. The following presents, in order of increasing depth below the surface, an overview of the hydrogeological units in the model area:

- *the Gambier Limestone*: an unconfined aquifer which ranges in thickness from 100 to 300 m (Waterhouse 1977). The unit comprises various facies of fossiliferous limestone of Tertiary age.
  The Gambier Limestone has an intrinsic primary permeability, and in many areas, there is a well-developed secondary permeability which has formed as a result of dissolution of the limestone. Numerous karst features are found throughout the study area.
  In the model area, groundwater flow is generally from the north towards the south or south-west with discharge at the coast. There are a number of significant coastal spring discharges occurring at Eight Mile Creek, Deep Creek and Piccaninnie Ponds. The total discharge from these springs has been estimated to be about 160 000 ML/year (Waterhouse 1977).
  The groundwater salinity is generally less than 500 mg/L, but there are some areas close to the coast where the salinity increases to about 1500 mg/L. The depth to the water table through the model area varies according to the topographic elevation and generally ranges from 5 to 25 metres below ground surface. Near the coast, the water table is quite shallow and can occur at depths of 1 to 2 metres.

- *the Dilwyn Formation Clay*: an aquitard, which comprises poorly consolidated marls and clays, commonly occurs as a low permeability unit between the unconfined aquifer and the underlying confined aquifer. The aquitard dips and generally thickens to the south.

- *the Dilwyn Formation Sand*: a confined aquifer underlying the Dilwyn Formation Clay aquitard. The unit comprises interbedded gravels, sands, silts and carbonaceous clays which are of early Tertiary age and are up to 800 metres in thickness.
  Groundwater flow is generally from the north east towards the south west in the study area. The potentiometric head of the confined aquifer is 5 to 20 metres higher than that of the unconfined aquifer through the model area, and artesian flows occur near the coast. The groundwater salinity is about 700 mg/L.

The recharge and discharge processes for both aquifers are illustrated in Figure 2. The unconfined aquifer receives recharge from lateral throughflow, from infiltration of rainfall throughout the study area and from upward leakage of groundwater from the confined aquifer. Recharge to the confined aquifer occurs in the area north of Mount Gambier, where the potentiometric head of the confined aquifer is lower than that of the unconfined aquifer.

MODFLOW AND VISUAL MODFLOW MODELS

MODFLOW is a three dimensional finite difference numerical groundwater flow model. It is widely used and was developed by the US Geological Survey (McDonald and Harbagh, 1988). In this modelling exercise, the finite difference groundwater flow equations were used to calculate the water level changes associated with lateral inflow, vertical leakages (both downward and upward) and varying groundwater extractions.

The Visual MODFLOW was developed by Waterloo Hydrological Software Inc in recent years. It is a pre-processor for quick generation of data files for the MODFLOW model. During this exercise, Visual MODFLOW was used as a tool to assist in generating the MODFLOW model grids, boundary conditions, observation well data, pumping wells and zones of differing hydrogeological properties. It was also used for establishing settings to run the model and to obtain rapid and convenient output results.

MODEL CONSTRUCTION

MODEL DOMAIN AND GRIDS

The model area as shown in Figure 1 is around 52 km (east to west) by 28 km (north to south). The northern boundary of the study area occurs just to the south of Mount Gambier, and this limit was chosen to avoid the modelling difficulties associated with the large groundwater extraction from the Blue Lake and the point source recharge of stormwater within the Mount Gambier township. The eastern boundary of the study area is the State Border of South Australia and Victoria. The AMG coordinates of the model domain are eastings 445000 to 497000, and northings 5787000 to 5815000.

The model area covers five separate groundwater management sub-areas, as shown in Figure 3, which form parts of the Lacepede–Kongorong and the Comaum-Caroline Prescribed Wells Areas. These management sub-areas include the entire Hundred of Kongorong and parts of the Hundreds of MacDonnell, Blanche and Benara within the Lacepede–Kongorong Prescribed Wells Area; and part of Zone 1A, which is a 20 kilometre wide management sub-area defined by the Groundwater (Border Agreement) Act 1985, of the Comaum-Caroline Prescribed Wells Area.

The rectangular shaped model grid has been discretised into 100 rows and 200 columns within the model domain. This provides a uniform cell size of 260 by 280 metres, which satisfies the model requirement and allows adequate consideration of the boundary conditions and the irrigation activity.

Vertically, the two aquifers and one aquitard as shown in Figure 2 were conceptualised in the model as three discrete layers as defined below:

Layer 1 the Gambier Limestone unconfined aquifer
Layer 2 the Dilwyn Formation Clay aquitard
Layer 3 the Dilwyn Formation Sand confined aquifer.

All three layers had varying thicknesses which were determined using available hydrostratigraphic information and the relevant ground elevations.

Figure 4 shows the ground surface elevation contours which were used in the model. These indicate that the topographic relief is generally low (rising to a maximum of 50 m above surrounding areas), with several north-west to south-east trending ridges. The highest points are the Mount Gambier and Mount Schank volcanic cones which rise to 190 and 120 m above sea level respectively.

The variation in thickness of the different layers, the unconfined aquifer, the aquitard and the confined aquifer, are shown respectively in Figures 5, 6 and 7. The thickness of the aquitard (Layer 2) was increased near the coast to satisfy the boundary conditions of the model, and this is discussed in more detail below.

The same grid size was applied to all three model layers resulting in a total of 20 000 finite difference cells in the model calculations.

BOUNDARY CONDITIONS AND INITIAL WATER LEVELS

Boundary conditions in the three model layers were assigned as follows:

- *Layer 1* (the unconfined aquifer). The groundwater flow in the Gambier Limestone aquifer is mainly from the north to the south and south-west, and three types of boundary conditions (no-flow, constant head and varying general head boundaries) were used for this layer as shown in Figure 8.

  The eastern and western edges of the model area were taken to be no-flow boundaries as the groundwater movement is essentially parallel to these edges.

The northern boundary of the model area was represented as a general head boundary to allow lateral groundwater flow into the area and to allow the water level to change in response to the extractions that occurs in adjacent areas. The general head magnitude was varied with time to reflect the observed groundwater level trends.

The southern boundary of the model area along the coast was simulated as a constant head boundary set at zero metres AHD. The saline interface at the coast was conceptualised in the model by increasing the thickness of the aquitard along the coast for a distance inland of about 3 kms to simulate the fresh water flow pattern. Figure 9(a) shows the conceptual interface line and the Figure 9(b) shows the modelled thickness of Layer 2.

Three main springs (Eight Mile Creek, Deep Creek and Piccaninnie Ponds) along the coast in the model area discharge an average total volume of about 110 000 ML/year of groundwater to the sea, as indicated by the monitored flow data from 1970 to the present time. This discharge of groundwater from the unconfined aquifer is considered to emanate via karst features developed within the Gambier Limestone. The additional discharge from other smaller outflows was not incorporated in the model due to the lack of flow data and accuracy of their locations.

Finite difference numerical model calculations assume porous medium flow and cannot handle preferential groundwater flow through such karst features. For this modelling study, general head boundaries were used to conceptualise this karstic groundwater flow and spring discharge as illustrated in Figure 10.

Whilst the orientation and extent of the karstic features within the Gambier Limestone is not accurately known, the locations of the general head boundary cells in the model as shown in Figure 8 were selected according to the location and density of known karstic features and from the configuration of the water level contours which indicate possible discharge areas. The elevation of the end flow point of the general head boundary, being the spring discharge location, was set at zero metres AHD (ie at sea level elevation) and the conductance between the inflow and outflow cells was adjusted to match the observed water level around the karst areas and the observed discharge from the springs. The conductance ranged from 300 to 1000 m^2/day. Factors affecting the magnitude of the conductance are the distance between the spring cells and the general head boundary cells, and the nature of the conduit flow.

- *Layer 2* (the aquitard): as only very small volumes of water flow laterally into and out of this layer due to its low permeability, no flow boundaries were assigned to the model edges in this layer.
- *Layer 3* (the confined aquifer) as shown in Figure 11, constant head boundaries were used for all the model edges in this layer to simulate the potentiometric head distribution in the aquifer.

HYDRAULIC PROPERTIES

The hydraulic parameters of the unconfined aquifer in the model domain were assigned from relevant data in previous reports and from a number of production testing results available for the area. These previous investigations indicate a great range in the hydraulic conductivity (K) from 10 to 300 m/day and in the specific yield (Sy) from less than 0.1 up to 0.25. These significant variations are due to the development of the secondary permeability resulting from preferential dissolution of the limestone. Based on the above information and to achieve the model calibration, a Sy of 0.1 was adopted for the entire model area and several zones with varying K from 0.5 to 90 m/day were used in the model as shown in Figure 12.

In the MODFLOW model, the leakage rates between the two aquifers are determined according to the thickness of the aquitard, the vertical hydraulic gradient over the aquitard and its vertical hydraulic conductivity (K_v). A K_v of 10^{-6} m/day was used uniformly in the model for the aquitard (Layer 2) based on the results of laboratory tests undertaken on cored samples of the Dilwyn Formation Clay taken in the Nangwarry area (K Brown, pers comm).

Hydraulic conductivities ranging from 0.5 to 10 m/day were assigned to the confined aquifer according to the distribution shown in Figure 13, with the adopted values being based on the limited hydraulic testing results available, general knowledge of the nature of the aquifer and its potentiometric head distribution. A uniform specific storage coefficient of 10^{-6}/m for the confined aquifer was used throughout the model domain. It should be noted that Visual Modflow requires that the storage data be input as specific storage (units 1/m), as opposed to the elastic storage coefficient which is the specific storage multiplied by the aquifer thickness.

VERTICAL RECHARGE AND EVAPOTRANSPIRATION

Vertical recharge was applied to the unconfined aquifer in the model area according to the distribution shown in Figure 14. The recharge rates vary from 0 to 90 mm per year, and were applied to the model over a 185 day period each year simulating the winter season from April to September. For Part Zone 1A, the recharge rates were adopted from Bradley et al (1995); whilst for the remainder of the area, the vertical recharge rates used to determine the Permissible Annual Volume (PAV) for each of the management sub-areas of the Lacepede-Kongorong Prescribed Wells Area were adopted.

The average evapotranspiration rates from Waterhouse (1977) were used for the summer irrigation season (October to March) and the winter recharge (April to September) periods, respectively being about 560 and 210 mm. A two metre extinction depth was used uniformly in the model.

GROUNDWATER USE AND ALLOCATION

Historical groundwater extraction data for the model area were difficult to compile given the absence of any long term records of groundwater use through the area.

Spatial distributions of the 1999 irrigation use and 1999 allocations were provided by the Department for Environment, Heritage and Aboriginal Affairs (DEHAA). This information was used, together with local knowledge of sites of irrigation activity, to determine the locations of extraction wells through the model area as shown in Figure 15.

The date of construction of the individual extraction wells was then used to determine the commencement of irrigation at the sites, and it was assumed that the use at each site (unless otherwise known from local knowledge) remained constant at the rate indicated by the 1998 usage data provided by DEHAA. This history of extraction from 1970 to 1999, as shown in Table 1 below, was used in the model for the calibration period.

Table 1 highlights the large increase in irrigation activity through the area since the late 1980s, with the increase being particularly significant around the time of prescription of the Lacepede-Kongorong Prescribed Wells Area.

Table 1 *Estimated Extraction Volumes And Rates From 1970 To 1999*

Year	Number of Extraction Wells	Extracted Volume (ML/yr)	Extraction Rate ** (m^3/day)
1970	1	17	97
1971	1	17	97
1972	1	17	97
1973	4	733	4075
1974	5	773	4292
1975	6	800	4442
1976	7	821	4560
1977	9	1063	5906
1978	9	1063	5906
1979	10	1075	5974
1980	19	1478	8211
1981	21	1683	9349
1982	26	2063	11 459
1983	28	2358	13 099
1984	28	2358	13 099
1985	28	2358	13 099
1986	29	2421	13 448
1987	31	2634	14 635
1988	35	3144	17 469
1989	39	3404	18 910
1990	49	4284	23 798
1991	51	4509	25 052
1992	54	4932	27 400
1993	57	5319	29 550
1994	70	7690	42 722
1995	82	10 220	56 778
1996	101	12 879	71 552
1997	150	19 782	109 901
1998	177	23 923	132 903
1999	181	24 639	136 883

** The extraction rate is the extracted volume taken over the 180 day irrigation season used in the model.

MODEL CALIBRATION AND VALIDATION RESULTS

STEADY STATE CALIBRATION

The first stage of the modelling involved a steady state run using different boundary conditions, hydraulic conductivities for both aquifers, varying the upward leakage from the confined aquifer and different vertical recharge rates for the unconfined aquifer over the entire model domain. Based on the understanding of the hydrogeological conditions in the model area, these parameters were then adjusted until there was a reasonable match between the determined and the observed water levels for the unconfined aquifer in the early 1970s (taken to be the pre-development conditions).

The accuracy of the steady state calibration was evaluated by considering the groundwater level elevations and the flow directions for both aquifers, and the average discharge from the three main springs.

These steady state water levels were then used as the initial groundwater levels (pre-pumping) for the transient calibration model run.

Changes in the parameters and boundaries made during the transient calibration model run were tested by undertaking additional steady state model runs.

TRANSIENT CALIBRATION

The transient model had a total simulation period of 30 years, representing a ‘real’ time duration beginning at the end of March 1970 and extending to the end of March 2000. Each year was divided into two stress periods, a summer irrigation season (from October to March) of 180 days duration and a winter, non-irrigation season (from April to September) of 185 days duration.

There is a reasonably comprehensive network of observation wells through the study area as shown in Figure 3. The majority of the observation wells have recorded groundwater levels for the unconfined aquifer from the early 1970s to the present time, and these wells were used as a reference for the transient calibration of the model.

The specific yield, hydraulic conductivities and vertical recharge rates were adjusted within reasonable limits to achieve an acceptable match between calculated and observed water levels, and between determined and actual discharge volumes of the coastal springs.

There was some difficulty in matching the decline in water levels in the unconfined aquifer from 1993 to 1999 though the model area. Reasonable calibration was achieved by reducing the vertical recharge rates by 30% to take into account the lower rainfall over this period.

The calibrated and observed water level contours for the unconfined aquifer for 1996 (Figure 16) show good agreement over most of the model area, except for the north-western part of the model domain where there is a lack of reliable monitoring data.

The calibrated and actual water level data for all the observation wells shown in Figure 16 are presented as hydrographs in Figures 17 to 22. A good match was obtained for most wells as indicated by the small difference between the observed and calibrated levels, and the similarity in the water level trends. A few wells located in karstic areas and near the coast indicate a poorer match, due most likely to the influence of preferential karst groundwater flow which cannot be determined by the model.

The discharges from the coastal springs have been measured since the 1970 and a comparison of the determined and actual volumes of discharge for each spring, as presented in Figure 23, indicates that a reasonable calibration was achieved with the modelled results.

The calibration results for the confined aquifer as shown in Figure 11 indicate good agreement between the modelled and observed potentiometric level contours.

In considering all the factors discussed above, it is believed that a reasonable calibration of the model was achieved and the model could be used for the required predictive modelling.

SENSITIVITY ANALYSIS

The sensitivity of the various parameters used in the model was examined in both the steady state and transient model runs.

As mentioned previously, the steady state model was run by adjusting the hydraulic conductivities of both aquifers, the vertical recharge to the unconfined aquifer, the inter-aquifer leakage and using different conceptual boundary conditions. The water levels in both the unconfined and confined aquifers were found to be more sensitive to their hydraulic conductivities rather than the vertical recharge input into the model.

Sensitivity analysis was also undertaken during the transient model runs. The following variations were considered:

- using a fixed head boundary along the northern edge of the model
- using a varying head boundary along the northern edge of the model
- increasing the existing extraction rates by 20%, 200% and 300%
- varying the specific yield of the unconfined aquifer
- not reducing the vertical recharge to the unconfined aquifer by 30% over the 1993 to 1999 period
- varying the evapotranspiration extinction depth from 2 to 1.5 metres.

The transient sensitivity analysis showed that the trend of water level decline in the unconfined aquifer was more likely caused by the water level change on the northern boundary of the model rather than the extraction volumes. The magnitude of maximum drawdown and recovery in each individual irrigation season are mostly controlled by the specific yield of the unconfined aquifer and also the magnitude of the extraction rates, rather than the vertical recharge.

MODEL LIMITATIONS

All groundwater models have limitations due to the availability of information, the nature of the hydrogeological conditions in the model area and the requirement for specific modelling results. It is important to recognise these limitations.

The following is a summary of the acknowledged limitations of this model:

- It is considered that the main limitation of the model is the inherent difficulty of modelling a karstic unconfined aquifer with both preferential and porous medium groundwater flow. It is difficult to numerically model such a karstic aquifer due to the large spatial variability in hydraulic conductivity and specific yield. This limitation may result in some calibration results not accurately matching observed data, due to the more uniform use of hydraulic conductivity and specific yield in the model area.

- The current version of Modflow does not have density dependent simulations to model the saline / fresh water interface flow. In this modelling exercise, the saline water and fresh water interface was simulated by using a low permeability layer near the coast and was achieved by increasing the thickness of Layer 2 in this area. Any seawater intrusion impacts were assessed by examining the time series water level data for observation wells located near the coast.

- There is some uncertainty regarding the accuracy of the extraction data used for the model calibration due to the absence of any long term records of groundwater use through the model area.

- There is a lack of observed water level and aquifer test data in the northwest corner of the model area. The predicted results in this area may therefore be less accurate than those in the better calibrated areas.

PREDICTIVE MODELLING

Once satisfactory calibration had been achieved, different transient model runs to examine the likely impacts of extracting additional volumes of groundwater in the area south of Mount Gambier were undertaken.

SCENARIOS FOR PREDICTIVE MODELLING

Predictive model runs over a 30 year period from 2000 to 2030 for six different scenarios of groundwater use through the model area were undertaken.

These scenarios were:

- *Scenario 1* Continuation of the current usage (about 24 600 ML/year)
- *Scenario 2* Use of all allocated groundwater (about 42 900 ML/year)
- *Scenario 3* Use of the full PAV (about 49 800 ML/year)
- *Scenario 4* Use of about 125% of the PAV (61 900 ML/year)
- *Scenario 5* Use of about 150% of the PAV (74 300 ML/year)
- *Scenario 6* Use of 200% of the PAV (99 600 ML/year)

The PAV used for the portion of Zone 1A in the model area was based on the vertical recharge determinations made by Bradley et al (1995). This reflects the revised PAV for Zone 1A which was recently adopted by the Minister for Water Resources.

It was necessary for scenarios 2 to 6 to include some additional extraction wells in each management sub-area, to take into account the situations either where existing allocations had not been used prior to the year 2000 or where there was some additional groundwater available for allocation in some of the management sub-areas. The location of existing and new irrigation wells used for the model scenarios is shown in Figure 24.

NORTHERN BOUNDARY CONDITIONS USED FOR PREDICTIVE MODELLING

The observed groundwater level monitoring data for the unconfined aquifer along the northern boundary of the model area indicate that there is a decline in water levels through this area. Two actual rates of water level decline are evident, a small average annual decline of 0.015 metres from 1970 to 1992 and a larger average annual decline of 0.1 metres from 1993 to the present time. The decline is particularly illustrated by the hydrographs for observation wells BLA 65 (Figure 17), MAC 6 (Figure 18), CAR 21 (Figure 20), and BEN 12, BLA 95, BLA 68 and CAR 43 (all shown in Figure 22). This decline is largely attributed to a reduction in rainfall and corresponding reduced recharge to the unconfined aquifer over the monitored period.

For the predictive modelling of all six scenarios, it was considered necessary to examine three possible longer term trends for the general head boundary used at the northern edge of the model as represented in Figure 25. These head conditions being:

- no decline in head
- a small decline in head of 0.015 metres, and
- a large decline in head of 0.1 metres.

RESULTS OF PREDICTIVE MODELLING

The results of the predictions for each scenario for the unconfined aquifer using the different head conditions at the northern boundary of the model have been assessed based on the following:

- Examination of the maximum drawdown at the end of the irrigation season in the year 2030, with the maximum drawdown being the difference between the recovered (end of winter) calibrated water level in 1999 and the water level at the end of the irrigation season in the year 2030.

- Examination of the residual drawdown at the end of the recovery period in the year 2030, with the residual drawdown being the difference between the recovered (end of winter) calibrated water level in 1999 and the water level at the end of the winter season in the year 2030.

- Examination of the predicted water levels in 16 unconfined aquifer observation wells with a long term monitoring record through the model area.

- Consideration of the water budgets for the different model runs.

- Variations in the discharges for the three coastal springs.

- The risk of seawater intrusion.

The predicted maximum drawdown contours, residual drawdown contours and the hydrographs of the 16 observation wells for each scenario, with the three different northern boundary head conditions, are presented in Appendices A to F and the results are discussed below.

For ease of comparison, the ranges in maximum drawdown and residual drawdown for the six model scenarios for each of the management sub-areas with the three different head conditions on the northern boundary are presented respectively in Tables 2 and 3.

Table 2 *Range In Maximum Drawdown In Each Management Sub-Area For the Model Scenarios*

	RANGE OF MAXIMUM DRAWDOWN FROM THE YEARS 2000 TO 2030 (metres)														
	Management Sub-Area														
	PART ZONE 1A			**PART HD MACDONNELL**			**PART HD BLANCHE**			**PART HD BENARA**			**PART HD KONGORONG**		
	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline
SCENARIO 1 (current use)	0–0.6	0–0.7	0–2.8	0–0.6	0–0.8	0–2.0	0.2–0.5	0.6–0.7	1.8–2.8	0.2–0.5	0.6–0.8	1.4–2.8	0–0.6	0–0.8	0–2.2
SCENARIO 2 (use of allocation)	0–1.0	0 – 1.2	0–2.8	0–1.0	0–1.2	0–2.2	0.2–0.9	0.5–1.2	2.3–2.8	0.2–1.0	0.5–1.2	1.6–3.0	0–1.2	0–1.2	0–2.7
SCENARIO 3 (use of PAV)	0–1.1	0–1.2	0–2.8	0–1.2	0–1.4	0–2.7	0.2–1.2	0.5–1.4	2.4–3.0	0.2–1.3	0.6–1.6	2.1–3.0	0–1.3	0–1.6	0–3.0
SCENARIO 4 (use of 125% PAV)	0–1.4	0–1.6	0 – 3.0	0–1.7	0–1.8	0 – 3.0	0.2–1.6	0.5–1.8	2.7–3.2	0.2–1.7	0.5–2.0	2.2–3.5	0–1.8	0–2.0	0–3.4
SCENARIO 5 (use of 150% PAV)	0–1.8	0–1.9	0–3.0	0–2.1	0–2.2	0–3.4	0.2–2.0	0.5–2.2	3.0–3.6	0.2–2.1	0.5–2.3	2.7–3.8	0–2.2	0–2.4	0–3.8
SCENARIO 6 (use of 200% PAV)	0–2.4	0–2.6	0–3.5	0–2.9	0–3.0	0–4.3	0.2–2.8	0.5–3.0	3.0–4.3	0.2–2.9	0.5–3.1	3.0–4.6	0–3.2	0–3.2	0–4.6

Table 3 *Range In Residual Drawdown In Each Management Sub-Area For The Different Scenarios*

	RANGE OF RESIDUAL DRAWDOWN FROM THE YEARS 2000 TO 2030 (metres)														
	Management Sub-Area														
	PART ZONE 1A			**PART HD MACDONNELL**			**PART HD BLANCHE**			**PART HD BENARA**			**PART HD KONGORONG**		
	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline	No Head Decline	Small Head Decline	Large Head Decline
SCENARIO 1 (current use)	0	0–0.4	0–2.8	0	0–0.3	0–1.6	0	0.3–0.4	1.6–2.8	0	About 0.4	1.2–2.8	0	0–0.3	0–1.8
SCENARIO 2 (use of allocation)	0–0.3	0–0.5	0–2.8	0–0.4	0–0.6	0–1.8	0.2–0.4	0.5–0.6	1.8–2.8	0.2–0.4	About 0.6	1.6–2.8	0–0.5	0–0.7	0–2.2
SCENARIO 3 (use of PAV)	0–0.3	0–0.5	0–2.8	0–0.6	0–0.8	0–2.1	0.2–0.6	0.5–0.8	1.9–2.8	0.2–0.7	0.5–0.8	1.8–2.8	0–0.7	0–0.9	0–2.4
SCENARIO 4 (use of 125% PAV)	0–0.5	0–0.7	0–2.8	0–0.9	0–1.1	0–2.4	0.2–0.9	0.5–1.1	2.1–2.8	0.2–1.0	0.5–1.2	2.1–2.8	0–1.0	0–1.2	0–2.6
SCENARIO 5 (use of 150% PAV)	0–0.7	0–0.9	0–2.8	0–1.2	0–1.4	0–2.7	0.2–1.2	0.5–1.4	2.3–2.9	0.2–1.2	0.5–1.4	2.4–3.0	0–1.3	0–1.5	0–2.9
SCENARIO 6 (use of 200% PAV)	0–1.1	0–1.3	0–2.8	0–1.8	0–2.0	0–3.3	0.2–1.8	0.5–2.0	2.6–3.4	0.2–1.8	0.5–2.0	3.0–3.4	0–2.0	0–2.2	0–3.4

Scenario 1 Water Level Results

For this prediction, it was assumed that the extractions through the model area would remain constant at the 1999 levels over the period from the year 2000 to 2030. The results are provided in Appendix A1 to A3.

No head decline on the northern boundary

The maximum drawdown at the end of the pumping season over the 30 year prediction period (Figure A1–1 in Appendix A1) indicates that there would be about 0.6 metres of drawdown through parts of the MacDonnell and Kongorong management sub-areas, and between 0.2 to 0.5 metres in the Benara and Blanche management sub-areas. There is 0 to 0.6 metres of drawdown in the Zone 1A management sub-area.

The residual drawdowns over the 30 year period (Figure A1–2 in Appendix A1) indicate no long term water level decline.

The hydrographs for the observation wells (Figures A1–3 to A1–6 in Appendix A1) indicate that the water levels reach a steady state soon after the year 2000.

Small head decline on the northern boundary

The introduction of the small head decline on the northern boundary resulted in an increase in the maximum drawdown through the area of about 0.2 metres, being particularly obvious but expected along the northern edge of the model area (Figure A2–1 in Appendix A2).

A residual drawdown ranging from 0 to 0.4 metres is evident through the model area (Figure A2–2 in Appendix A2).

The hydrographs for the observation wells (Figures A2–3 to A2–6 in Appendix A2) indicate a slight longer term water level decline throughout the area over the prediction period.

Large head decline on the northern boundary

With the large head decline on the northern boundary, there was a noticeable increase in the maximum drawdown throughout the area which generally ranged from 0.4 to 2.8 metres and increased towards the northern edge of the model area (Figure A3–1 in Appendix A3).

The residual drawdowns also increased throughout the area with a longer term decline of between 0.2 and 2.8 metres (Figure A3–2 in Appendix A3).

The hydrographs for the observation wells (Figures A3–3 to A3–6 in Appendix A3) highlight a longer term water level decline. It is also apparent that the rate of decline continues well beyond the prediction period.

Scenario 2 Water Level Results

This scenario assumed that all the water allocated was extracted over the 30 year prediction period. The results are provided in Appendix B1 to B3.

No head decline on the northern boundary

The maximum drawdown at the end of the pumping season over the 30 year prediction period (Figure B1–1 in Appendix B1) indicates that there would be about 1.0 metre of drawdown through parts of the MacDonnell and Kongorong management sub-areas, and generally between 0.2 to 1.0 metres in the rest of the area.

The residual drawdowns over the 30 year period (Figure B1–2 in Appendix B1) indicate a water level decline exceeding 0.4 metres in the western half of the model area over the prediction period. This is mainly the result of the activation of the larger number of unused allocations in the western part of the model area.

The hydrographs for the observation wells (Figures B1–3 to B1–6 in Appendix B1) indicate that the water levels initially decline in response to the increased extractions but reach steady state conditions generally by the year 2005.

Small head decline on the northern boundary

The introduction of the small head decline on the northern boundary resulted in an increase in the maximum drawdown through the area of about 0.2 metres, particularly in parts of the MacDonnell and Kongorong management sub-areas (Figure B2–1 in Appendix B2).

The residual drawdowns also increased, especially in the western part of the model area and along the northern boundary of the area (Figure B2–2 in Appendix B2), with a decline of about 0.6 metres.

The hydrographs for the observation wells (Figures B2–3 to B2–6 in Appendix B2) indicate a slight longer term water level decline throughout the area over the prediction period, with no indication of the water levels reaching a steady state condition.

Large head decline on the northern boundary

With the large head decline on the northern boundary, there was a noticeable increase in the maximum drawdown throughout the area which generally ranged from 0.6 to 2.8 metres and increased towards the northern edge of the model area (Figure B3–1 in Appendix B3).

The residual drawdowns also increased throughout the area with a longer term decline of between 0.2 and 2.8 metres (Figure B3–2 in Appendix B3).

The hydrographs for the observation wells (Figures B3–3 to B3–6 in Appendix B3) highlight the longer term water level decline. It is again apparent that the rate of decline continues well beyond the prediction period.

Scenario 3 Water Level Results

This scenario assumed that all the PAV was allocated and was extracted over the 30 year prediction period. The results are provided in Appendix C1 to C3.

No head decline on the northern boundary

The predicted maximum drawdown contours at the end of the pumping season over the 30 year prediction period (Figure C1–1 in Appendix C1) indicate that there would be about 1.0 to 1.2 metres of drawdown through most of the Kongorong management sub-area and the southern part of the Benara management sub-area. In the MacDonnell management sub-area, the drawdown is generally between 0.8 and 1.2 metres, and generally ranges from 0.2 to 1.1 metres in the remainder of the area.

The residual drawdowns over the 30 year period (Figure C1–2 in Appendix C1) again indicate a water level decline in the western half of the model area over the prediction period of between 0.2 and 0.6 metres. This indicates the increased extraction in this part of the model area.

The hydrographs for the observation wells (Figures C1–3 to C1–6 in Appendix C1) indicate that the water levels initially decline in response to the increased extractions but reach steady state conditions generally by the year 2005.

Small head decline on the northern boundary

With the small head decline on the northern boundary, the maximum drawdown through the area ranges from 0.2 to 1.6 metres, with the greatest drawdown occurring through parts of the Kongorong management sub-area (Figure C2–1 in Appendix C2).

The residual drawdowns also increased to about 0.8 metres through parts of the Kongorong management sub-area and to about 0.5 metres along the northern boundary of the area (Figure C2–2 in Appendix C2).

The hydrographs for the observation wells (Figures C2–3 to C2–6 in Appendix C2) indicate a slight longer term water level decline throughout the area over the prediction period, with no indication of the water levels reaching a steady state condition.

Large head decline on the northern boundary

The large head decline on the northern boundary again resulted in a noticeable increase in the maximum drawdown throughout the area which generally ranged from 0.6 to 3.0 metres and increased towards the northern edge of the model area (Figure C3–1 in Appendix C3).

The residual drawdowns show a longer term decline of 0.2 metres along the coast and increasing to about 2.8 metres along the northern boundary of the model area (Figure C3–2 in Appendix C3).

The hydrographs for the observation wells (Figures C3–3 to C3–6 in Appendix C3) again highlight the longer term water level decline and it is apparent that the rate of decline continues well beyond the prediction period.

Scenario 4, 5 and 6 Water Level Results

The simulations for scenarios 4, 5 and 6 involved increasing the groundwater extractions to 125%, 150% and 200% of the PAV in each of the management sub-areas. This seemed a reasonable approach to determine whether a proportion of the lateral throughflow could be used in the area, given that the PAV is based on the vertical recharge to the unconfined aquifer. The results for the scenarios are provided in Appendices D, E and F.

The following provides a comparison of the results for scenarios 3, 4, 5 and 6 for the three different head conditions used for the northern boundary conditions.

No head decline on the northern boundary

The results show that centre of the cone of the maximum drawdown at the end of the 30 year prediction period (Figures C1–1, D1–1, E1–1 and F1–1 in Appendices C1, D1, E1 and F1) occurs in the Kongorong management sub-area. The magnitude of the drawdown in this area increases from 1.2 to 3.2 metres as the extractions increase from the full PAV to 200% of the PAV.

The main area of residual drawdown after 30 years occurs in the western part of the model area (Figures C1–2, D1–2, E1–2 and F1–2 in Appendices C1, D1, E1 and F1) with the residual drawdown increasing from 0.6 to 2.0 metres as the extraction increase.

The representative hydrographs for each of the extraction scenarios are shown in the sets of Figures C1–3 to C1–6, D1–3 to D1–6, E1–3 to E1–6 and F1–3 to E1–6 in Appendices C1, D1, E1 and F1. All the results show that steady state conditions occur within a few years after commencement of extraction in the year 2000. The main differences between the results are the varying the time interval to reach steady state conditions, the magnitude of both the seasonal drawdown and the residual drawdown between 2000 and 2030.

Small head decline on the northern boundary

The maximum and residual drawdowns at the end of the 30 year prediction period for each scenario are respectively shown in Figures C2–1, D2–1, E2–1 and F2–1 and in Figures C2–2, D2–2, E2–2 and F2–2 in Appendices C2, D2, E2 and F2.

The main area of drawdown occurs in the western part of the model area. In comparison with the results with no decline on the northern boundary, the magnitude of the drawdowns increased by about 0.1 to 0.3 metres. The largest maximum drawdowns ranged from 1.6 to 3.2 metres, and the largest residual drawdowns ranged from 0.8 to 2.2 metres.

The representative hydrographs for these predictions as shown in the sets of Figures C2–3 to C2–6, D2–3 to D2–6, E2–3 to E2–6 and F2–3 to F2–6 in respective Appendices C2, D2, E2 and F2. All the results show a longer term decline in water levels and which do not appear to be reaching steady state conditions. The main differences between the results are the magnitude of both the seasonal drawdown and the residual drawdown over the prediction period.

Large head decline on the northern boundary

The maximum and residual drawdowns at the end of the 30 year prediction period for each scenario are respectively shown in Figures C3–1, D3–1, E3–1 and F3–1 and in Figures C3–2, D3–2, E3–2 and F3–2 in Appendices C3, D3, E3 and F3.

The representative hydrographs for these predictions are shown in the sets of Figures C3–3 to C3–6, D3–3 to D3–6, E3–3 to E3–6 and F3–3 to F3–6 in respective Appendices C3, D3, E3 and F3.

In comparison with the results for the same scenarios with the small head decline on the northern boundary, the main differences are that the magnitude of the maximum and residual drawdowns have increased significantly, especially in the western part of the model area.

WATER BUDGETS FOR THE DIFFERENT SCENARIOS

To gain an understanding of the significance of the various model inputs and outputs and their respective changes with time under the different extraction scenarios, the water budget for the end of the calibration period in the year 2000 was compared with the water budget for each model scenario in the year 2030. A summary of this data, for each of the different head conditions used for the northern boundary of the model area, is presented in Appendix G.

These comparisons generally indicate that as the extractions through the area increase, there is a corresponding increase in the volume of groundwater inflow across the northern boundary of the model area with reductions in the discharges from the coastal springs, outflows to the sea and the Glenelg River, and reduced evapotranspiration losses. The upward leakage from the confined aquifer into the unconfined aquifer increases only marginally as the extractions increase, with the volumes of increased leakage being insignificant when compared with the other components of the water budget.

The most significant changes with the increased extractions are:

- the increase in groundwater inflow across the northern boundary of the model area. The source of this groundwater would be from the area through Mount Gambier and to the north, where (as discussed previously) a longer term decline in groundwater levels in the unconfined aquifer is evident. Increasing the outflow of groundwater from this area would exacerbate these declining trends in water levels.

- the decreased discharges from the coastal springs. This issue is discussed separately in the following section of the report.

- the decreased discharges to the sea. The modelled results indicate that there would be about a 30% reduction in the discharge of groundwater from the unconfined aquifer to the sea. Given the lack of knowledge of the environmental significance of the present groundwater outflows, such an impact is difficult to assess and would require further investigation. The reduced discharges to the sea also have the potential to cause the saline and fresh water interface to migrate further inland. This is discussed in more detail in a later section of the report.

- The water budgets presented in Appendix G also indicate that with the increased extractions through the area, the difference between the total inflow and total outflow increases. This indicates that an increasing volume of groundwater is being removed from storage. This is illustrated by the continued rate of water level decline in the unconfined aquifer for the higher extractions as discussed in the previous section of the report.

- Comparisons of the sets of results for the different head conditions used for the northern boundary of the model indicate that as the head in the unconfined aquifer declines, there is a reduced volume of groundwater inflow across the northern boundary. This is expected as the hydraulic gradients for the unconfined aquifer, which govern this flow, are reduced. The main consequences of the reduced inflows across the northern boundary are:

- the discharges from the coastal springs are further reduced
- the discharges to the sea and the Glenelg River are similarly further reduced
- there is an increased difference between the total inflow and total outflow, which would result in additional volumes of groundwater being removed from storage and thereby causing larger longer term water level declines in the unconfined aquifer.

CHANGES IN SPRING DISCHARGES FOR THE DIFFERENT SCENARIOS

The predicted changes in the discharges from the three main springs, Eight Mile Creek, Deep Creek and Piccaninnie Ponds, for each model scenario with the different head conditions used for the northern boundary were examined to assess the significance of the outflow reductions with the increased groundwater extractions in the study area.

A summary of the predicated discharges for each spring for the different scenarios at the end of the predictive period (year 2030) and the discharge at the end of calibration period in the year 2000 is provided in Table 4. The results are also graphically presented for each of the northern boundary head conditions in Figures 26 to 28.

The model results indicate the discharges from these springs will decrease with time as the extractions increase regardless of the head conditions adopted at the northern boundary.

The most significantly affected springs are Eight Mile Creek and Deep Creek, where the discharges for the largest extraction scenario with the highest head decline on the northern boundary could be respectively reduced by about 44% and 49%. The discharges from Piccaninnie Ponds are not as significantly affected due to the reduced number of extraction wells occurring through its area of influence.

The results also indicate that some reduction in discharge from each of the springs is anticipated even if there is no additional groundwater made available for extraction in the area.

The consequence of the reduction in the discharges from these coastal springs on either the terrestrial or marine environment is an issue which should be examined by specialists in these related fields.

Table 4 *Predicted Discharges From The Three Main Springs*

	EIGHT MILE CREEK	**DEEP CREEK**	**PICCANINNIE PONDS**
	Flow at the end of calibration period – year 2000 (ML/Year)		
	53 009	**21 226**	**23 826**
	Flow at the end of year 2030 (ML/Year)		
No head decline on the northern boundary			
Scenario 1 (current use)	51 559	20 376	23 678
Scenario 2 (use of allocation)	48 787	19 116	23 312
Scenario 3 (use of PAV)	48 110	18 757	23 244
Scenario 4 (use of 125% PAV)	46 184	17 848	23 018
Scenario 5 (use of 150% PAV)	44 233	16 924	22 789
Scenario 6 (use of 200% PAV)	40 263	15 035	22 329
Small head decline on the northern boundary			
Scenario 1 (current use)	49 989	19 772	23 109
Scenario 2 (use of allocation)	47 203	18 505	22 742
Scenario 3 (use of PAV)	46 338	18 141	22 673
Scenario 4 (use of 125% PAV)	44 584	17 226	22 447
Scenario 5 (use of 150% PAV)	42 623	16 229	22 218
Scenario 6 (use of 200% PAV)	38 636	14 399	21 757
Large head decline on the northern boundary			
Scenario 1 (current use)	41 077	16 338	19 900
Scenario 2 (use of allocation)	38 214	15 022	19 527
Scenario 3 (use of PAV)	37 491	14 635	19 457
Scenario 4 (use of 125% PAV)	35 503	13 688	19 227
Scenario 5 (use of 150% PAV)	33 498	12 731	18 995
Scenario 6 (use of 200% PAV)	29 474	10 809	18 531

Risk Of Seawater Intrusion

The model results, as mentioned previously, indicate that the discharges of groundwater from the unconfined aquifer to the sea would decrease as the extractions increase. This raises the concern whether seawater intrusion could be a potential risk in areas close to the coast.

In order to assess the modelled impacts, the time series data for the observation wells located close to the coast were examined, and the depths of the saltwater interface were determined for the years 1970, 2000 and 2030 using the Herzberg relationship.

These results indicated that for the maximum extraction scenario (ie 200% PAV) with a small head decline on the northern boundary of the model, the saltwater interface at the end of recovery in the year 2030 would be raised from its determined elevation of -240 metres (AHD) in the year 1970 to about -120 metres (AHD) at a distance of 3 km inland from the coast. For scenario 3 (ie full use of the PAV), under the same northern head boundary condition, the elevation of the saltwater interface at the end of recovery in the year 2030 would be at about -150 metres (AHD). The corresponding elevations of the saltwater interface at the end of the extraction season in the year 2030, for the same scenarios, would respectively be about -70 and -140 metres (AHD).

The higher elevations of the saltwater interface with the larger extractions indicate that there is a risk in areas close to the coast to existing and potential groundwater users, particularly if the extraction wells source their supply from deeper parts of the unconfined aquifer.

There is also a potential risk that the coastal spring discharges could be influenced by the raised saltwater interface with an increased salinity of the discharge. The latter impact would be subject to the depth of the karstic source of the spring discharge, which is not accurately known.

DISCUSSION OF MODELLING RESULTS

POTENTIAL TO USE A PROPORTION OF THE LATERAL GROUNDWATER THROUGHFLOW

The predictive modelling for the six extraction scenarios using the different head conditions for the unconfined aquifer on the northern boundary of the model indicates that varying impacts can be expected by increasing the extractions in the model area.

It is particularly obvious that the head condition used on the northern boundary can significantly affect the various results. Whilst the head conditions using no decline and a large decline in water levels needed to be examined, it is considered that the results using the small water level decline on the northern boundary are likely to be the most representative of the longer term conditions. These results have therefore been used to assess the potential to use a proportion of the lateral throughflow in the model area.

The range in maximum drawdowns and residual drawdowns in each management sub-area for the different scenarios have been respectively summarised in Tables 5 and 6.

The maximum drawdowns shown in Table 5, which are the difference between the recovered calibrated water level in 1999 and the water level at the end of the irrigation season in the year 2030, range from 0 to 3.2 metres throughout the model area for the different model scenarios. The most significant drawdowns occur in the MacDonnell, Kongorong and Benara management sub-areas, due mainly to the additional extractions post-2000 and partly by the lower hydraulic conductivity of the unconfined aquifer in some of this area. The scenario 3 results (full use of the PAV) indicate that the maximum drawdowns are likely to vary from about 1.2 metres in Zone 1A to about 1.4 and 1.6 metres in the remainder of the area. This is considered to be an acceptable impact.

As extractions increase for scenarios 4, 5 and 6, the maximum drawdowns increase generally to 2 to 3 metres for the highest extractions. Such drawdowns may be unacceptable due to interference with existing water supply wells that are completed at shallow depths in the unconfined aquifer.

Table 5 *Range Of Maximum Drawdowns In Each Management Sub-Area For The Different Scenarios With A Small Head Decline On The Northern Boundary*

	RANGE OF MAXIMUM DRAWDOWN FROM THE YEARS 2000 TO 2030 (metres)				
	Management Sub-Area				
	PART ZONE 1A	**PART HD MACDONNELL**	**PART HD BLANCHE**	**PART HD BENARA**	**PART HD KONGORONG**
SCENARIO 1 (current use)	0–0.7	0–0.8	0.6–0.7	0.6–0.8	0–0.8
SCENARIO 2 (use of allocation)	0–1.2	0–1.2	0.5–1.2	0.5–1.2	0–1.2
SCENARIO 3 (use of PAV)	0–1.2	0–1.4	0.5–1.4	0.6–1.6	0–1.6
SCENARIO 4 (use of 125% PAV)	0–1.6	0–1.8	0.5–1.8	0.5–2.0	0–2.0
SCENARIO 5 (use of 150% PAV)	0–1.9	0–2.2	0.5–2.2	0.5–2.3	0–2.4
SCENARIO 6 (use of 200% PAV)	0–2.6	0–3.0	0.5–3.0	0.5–3.1	0–3.2

The residual drawdowns shown in Table 6, which are the difference between the recovered calibrated water level in the year 1999 and the recovered water level at the end of the non-pumping period in the year 2030, generally range from 0 to 2.2 metres. Again, the largest residual drawdowns occur in the Benara and Kongorong management sub-areas. The residual drawdowns for scenario 3 (full use of the PAV) generally range from about 0.5 to 0.8 metres, which is equivalent to an annual long term water level decline of about 0.025 metres. The annual long term water level decline increases to about 0.07 metres for scenario 6 (use of 200% of the PAV).

Table 6 *Range Of Residual Drawdowns In Each Management Sub-Area For The Different Scenarios With A Small Head Decline On The Northern Boundary*

	RANGE OF RESIDUAL DRAWDOWN FROM THE YEARS 2000 TO 2030 (metres)				
	Management Sub-Area				
	PART ZONE 1A	**PART HD MACDONNELL**	**PART HD BLANCHE**	**PART HD BENARA**	**PART HD KONGORONG**
SCENARIO 1 (current use)	0–0.4	0–0.3	0.3–0.4	About 0.4	0–0.3
SCENARIO 2 (use of allocation)	0–0.5	0–0.6	0.5–0.6	About 0.6	0–0.7
SCENARIO 3 (use of PAV)	0–0.5	0–0.8	0.5–0.8	0.5–0.8	0–0.9
SCENARIO 4 (use of 125% PAV)	0–0.7	0–1.1	0.5–1.1	0.5–1.2	0–1.2
SCENARIO 5 (use of 150% PAV)	0–0.9	0–1.4	0.5–1.4	0.5–1.4	0–1.5
SCENARIO 6 (use of 200% PAV)	0–1.3	0–2.0	0.5–2.0	0.5–2.0	0–2.2

Whilst these drawdowns may not appear to be overly excessive, given the general large saturated thickness of the unconfined aquifer in the area, there are other impacts which need to be considered. These are the reductions in discharges from the coastal springs, reductions in discharges to the sea and the Glenelg River, the risk of inland migration of the saltwater interface and the increased groundwater inflows across the northern boundary of the model area. These impacts are discussed separately below.

The model predicts that there will be a reduction in the discharges from the coastal springs. The impacts of these reduced discharges need some environmental comment which is beyond the scope of this modelling exercise. It is obvious though, that as the extractions increase, the discharges from the springs are further reduced.

There is also a reduced discharge of groundwater to the sea and, as discussed previously, there may be some risk of seawater intrusion. This risk increases as the extractions in the area extend beyond the current PAV in the management sub-areas.

Whilst the model predicts some decrease in discharge of groundwater from the unconfined aquifer to the Glenelg River, the reductions are not considered to be significant.

The additional groundwater inflow across the northern boundary of the model as the extractions are increased is of some concern, particularly given that this groundwater would be sourced from the general Mount Gambier area where a longer term decline in groundwater levels is evident.

The current PAV in each management sub-area is based on the assessed vertical recharge to the unconfined aquifer. Increasing the PAVs beyond their current limits therefore corresponds to using some of the lateral groundwater throughflow in the unconfined aquifer.

With consideration of all the model results, increasing the extractions beyond the current PAV in each management sub-area is likely to cause some potential adverse impacts and should therefore not be implemented until at least the levels of use have approached the PAV in each management sub-area and there has been adequate monitoring of such extraction.

COMMENT ON THE APPROPRIATENESS OF THE CURRENT MANAGEMENT AREAS

The boundaries of the current management sub-areas within the model area, as shown in Figure 3, are based either on the Hundreds occurring within the area or on Zone 1A of the Designated Area defined by the Groundwater (Border Agreement) Act. Whilst the Hundred boundaries are readily recognisable, the western boundary of Zone 1A is not well defined being a fixed distance of 20 kms from the South Australia and Victoria State Border.

Although alternate management sub-area boundaries could be considered, such as varying vertical recharge areas, zones of varying hydraulic conductivity of the unconfined aquifer and possibly zones of varying groundwater allocation, it would be difficult to precisely define these different boundaries and the boundaries would less recognisable.

It is considered therefore that the current management sub-areas be retained until further monitoring and assessment data are available to reconsider such options.

REVIEW OF GROUNDWATER MONITORING NETWORK

Part of this study required an assessment of the current groundwater monitoring network with recommendations for any enhancements.

To assess the adequacy of the spatial distribution of the current monitoring network, the locations of existing and new irrigation wells, used for the model scenarios and the current observation wells were plotted through the study area as shown in Figure 29.

It is considered that the current water level monitoring network should be expanded by the addition of a further 10 to 12 observation wells completed in the unconfined aquifer. The majority of these wells should be located through the western part of the study area, particularly in the Hundreds of Kongorong and Benara, where the model results indicate that the likely impacts of future increased irrigation will be more noticeable.

These additional monitoring wells should be unequipped wells to avoid, as has occurred in the past, any pumping influences on the water levels.

It is uncertain whether these additional monitoring wells need to be specifically constructed or whether existing unequipped wells may be located at the specified sites. A field survey would be needed to assess the requirement for the drilling of any new wells.

In addition to the above water level monitoring wells, it is considered that there is a need to enhance the groundwater salinity monitoring network. This could be achieved by supplementing the current network with about 12 to 15 privately owned water supply wells through the area.

In the longer term, it is anticipated that some additional monitoring of the confined aquifer through the area will also be required. At this stage, this is not considered to be a priority given the very low use of this groundwater resource.

It is not possible to provide a cost for the additional monitoring proposed until a field survey is undertaken to establish whether appropriate wells exist to supplement the current observation network.

DISCUSSION ON GROUNDWATER MONITORING CRITERIA

Apart from having a groundwater monitoring network, it is also prudent to have some criteria against which the monitoring data can be assessed.

The model results indicate that groundwater levels may decline by about 0.03 metres per annum should extractions reach the current PAV in each of the management sub-areas. It is recommended therefore that such a longer term decline be adopted as a longer term indicator of the appropriateness of the model results and the level of stress on the unconfined aquifer groundwater resources.

It is also recommended that the monitoring of the discharges of the coastal springs be maintained (currently undertaken by the South East Water Conservation and Drainage Board). It is considered that these spring discharges reflect the integrated impacts on the groundwater resources of the unconfined aquifer, which could comprise increased groundwater extractions, changes in land use affecting vertical recharge to the aquifer and even climatic variability. It is difficult to establish an actual monitoring criteria for these spring discharges but a continuing reduction of spring discharge between 100 and 200 ML per year should be viewed as a need for investigation.

In relation to groundwater quality monitoring criteria, it is recommended that an increase in groundwater salinity of 10 mg/L per annum over a minimum period of five years be used as a trigger for review and possible investigation.

It is recommended that all monitoring data (groundwater levels, groundwater quality, coastal spring discharges and groundwater extractions) be reviewed at intervals not exceeding three years.

SUMMARY AND CONCLUSIONS

A numerical finite difference groundwater flow (MODFLOW) model was developed to examine the potential to use a proportion of the lateral throughflow in the unconfined aquifer in the area south of Mount Gambier.

The model was calibrated for both steady-state and transient conditions, using long term monitoring data for observation wells through the area and measured discharges from three coastal springs (Deep Creek, Eight Mile Creek and Piccaninnie Ponds). Once satisfactory model calibration had been achieved, six predictive model runs for a 30 year period were run to test different scenarios of groundwater extraction from the unconfined aquifer. Three different water level trends for the unconfined aquifer on the northern boundary of the model were used for each of the extraction scenarios given the observed water level trends in this area.

The model results using a small water level decline on the northern boundary of the model were considered to be the most appropriate to assess the potential to use a proportion of the lateral throughflow in the unconfined aquifer.

The predictive model results for the different extractions through the area indicate that as the extractions increase there will be:

- increased drawdowns in the groundwater levels in the unconfined aquifer. These drawdowns are likely to be manageable for extractions up to the current PAV in each management sub-area, but higher extractions may cause some unacceptable interference impacts to existing groundwater users.

- reduced discharges from the coastal springs. The impacts of such reductions on either the terrestrial or marine environment are uncertain and expert comment by specialists in these related fields is required before any increase in the current PAV in each management sub-area is considered.

- reduced groundwater discharges from the unconfined aquifer to the sea. The higher elevations of the saltwater interface with the larger extractions indicate that there is a risk in areas close to the coast to existing and potential groundwater users, particularly if the extraction wells source their supply from deeper parts of the unconfined aquifer.
  There is also a potential risk that the coastal spring discharges could be influenced by the raised saltwater interface with an increased salinity of the discharge. The latter impact would be subject to the depth of the karstic source of the spring discharge, which is not accurately known.

- increased groundwater inflows across the northern boundary of the model area. Such inflows would emanate from the general Mount Gambier area where there are current concerns regarding the declining groundwater levels in the unconfined aquifer. The additional outflow of groundwater from this area would exacerbate this water level decline.

- reduced groundwater discharges from the unconfined aquifer to the Glenelg River. These reductions are not considered to be significant, even for the highest levels of extraction through the area.

- slight increases in the upward leakage of groundwater from the confined aquifer to the unconfined aquifer. These increases are not considered to be significant, when compared with the other water budget components of the unconfined aquifer, and it is considered unlikely that this will result in any adverse impact on the groundwater resources in either aquifer.

It is concluded that increasing the current PAV in each of the management sub-areas, that is using a proportion of the lateral groundwater throughflow in the unconfined aquifer, would result in some potentially adverse impacts.

RECOMMENDATIONS

It is recommended that:

1. The current PAV in each management sub-area (that is, the Hundreds of Benara and Kongorong, the part Hundreds of Blanche and MacDonnell, and Zone 1A) be retained at the present level and not be increased.

2. Monitoring of groundwater levels and salinity in the unconfined aquifer be increased through the area with the addition of a number of new observation wells. This will require a field survey in parts of the area to assess whether any existing wells could be suitable for this purpose or whether new wells need to be constructed.

   This increased monitoring is needed to assess the longer term impacts of groundwater extractions and to determine the accuracy of the groundwater modelling results.

3. Monitoring of the coastal spring discharges, as currently undertaken by the South Eastern Water Conservation and Drainage Board, be maintained.

4. Groundwater levels and salinity through the area, and the discharges from the coastal springs be used as sustainability indicators for the groundwater resources of the unconfined aquifer in the area south of Mount Gambier.

   The data for these parameters should be collectively reviewed at intervals not exceeding three years and compared against the levels of groundwater extraction in each of the management sub-areas.

   The groundwater level monitoring data should reviewed on an annual basis and the results reported to the South East Catchment Water Management Board.

5. There be annual compilation of the groundwater extraction data for each management sub-area. This compilation should be in a GIS format to enable ready determination of the spatial distribution of irrigation activity.

6. The current management sub-areas be retained until further monitoring and assessment data are available.

7. Further specific investigations be undertaken to increase the knowledge base for the area, particularly:

   - Determining the significance of the discharges from the coastal springs on both the terrestrial and marine environments.

   - Determining the dependence of the coastal wetland environments on groundwater level elevations.

   - Quantifying the groundwater extractions in the management sub-areas.

   - Determining the current position of the salt-water interface within the unconfined aquifer adjacent to the coast, and assessing in more detail the likelihood of adverse water quality impacts to existing and potential groundwater users, and the wetlands in this area, resulting from increased elevations of the salt-water interface due to groundwater extractions. This should also include the establishment of a suitable network of monitoring wells to determine both the seasonal variations and any longer term changes in the elevation of the salt-water interface.

   - Undertaking some additional model runs to determine the potential impacts of a larger head decline occurring along the northern boundary of the model area for various extraction scenarios (eg full use of current allocations, full use of the PAVs and use of 150% of the PAVs).

ACKNOWLEDGEMENTS

The authors sincerely thank:

- Don Armstrong for his advice and review of the conceptual construction of the model
- Phil Gorey from the Department for Environment, Heritage and Aboriginal Affairs for the provision of and GIS compilation of the irrigation usage and allocation data
- Jeff Lawson for compiling all the irrigation usage and allocation data for use in the model, and
- Keith Brown for assistance with development of the model.

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Appendix A1

Scenario 1: Results with no head decline on the northern boundary

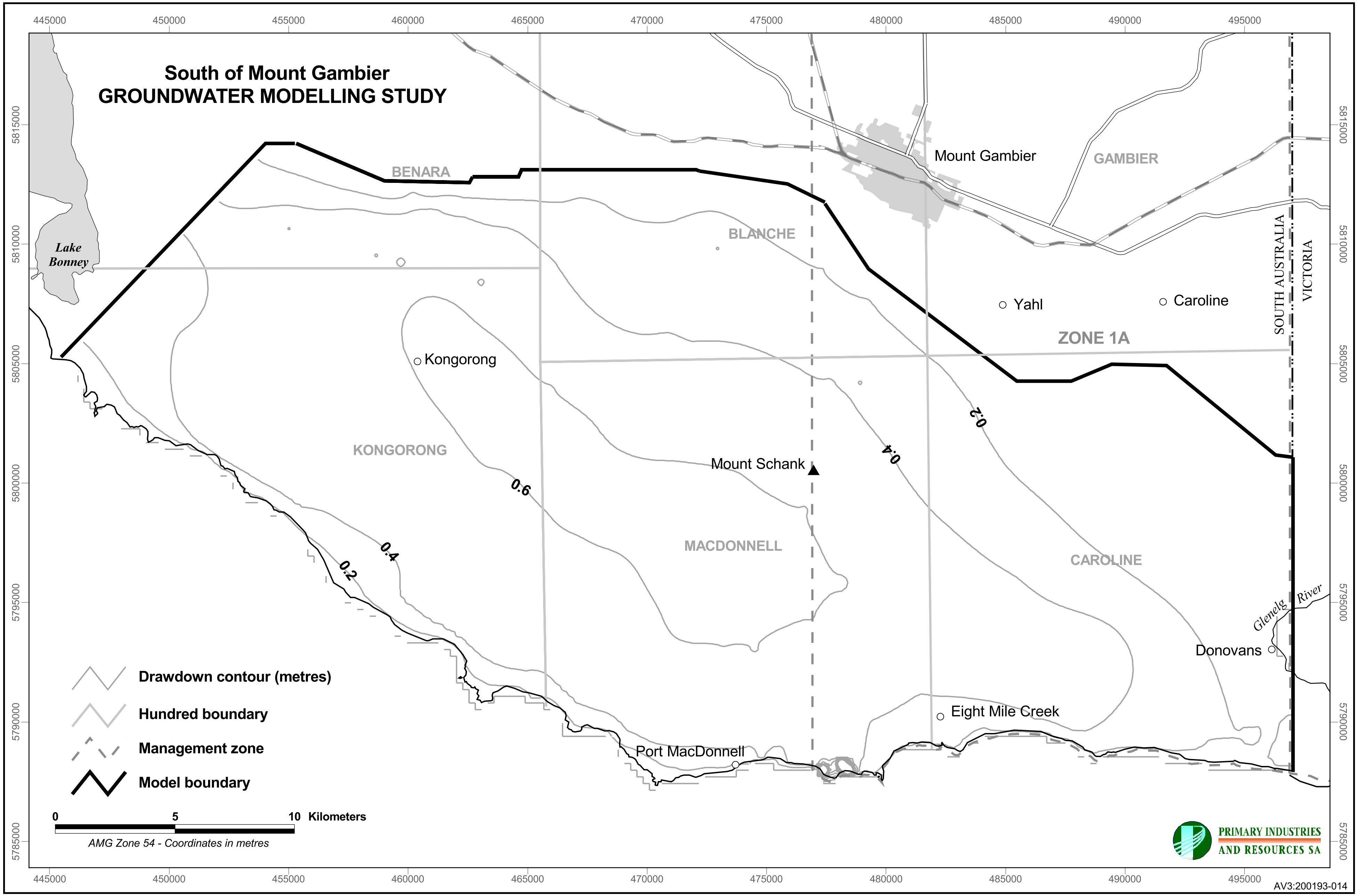


Figure A1-1   *Predicted maximum drawdown contours for scenario 1 (2000 to 2030) with no head decline on the northern boundary.*

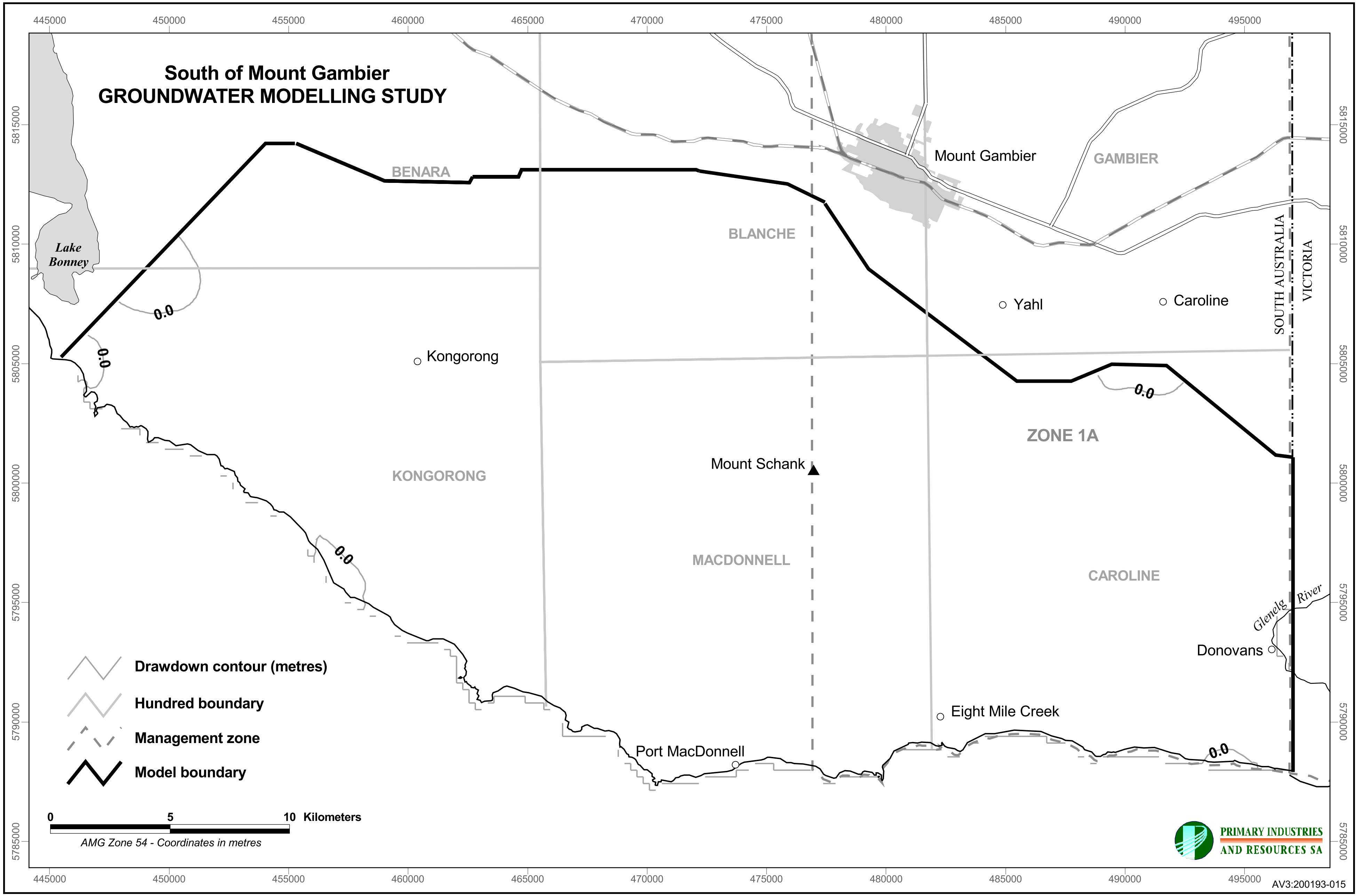
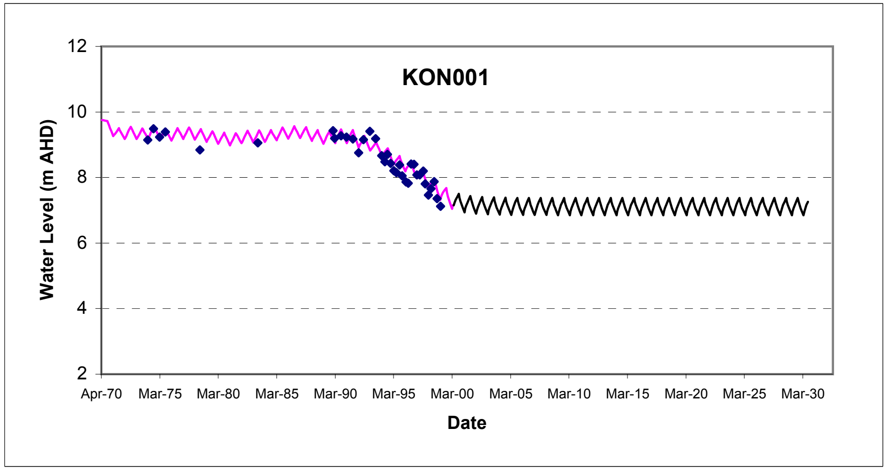
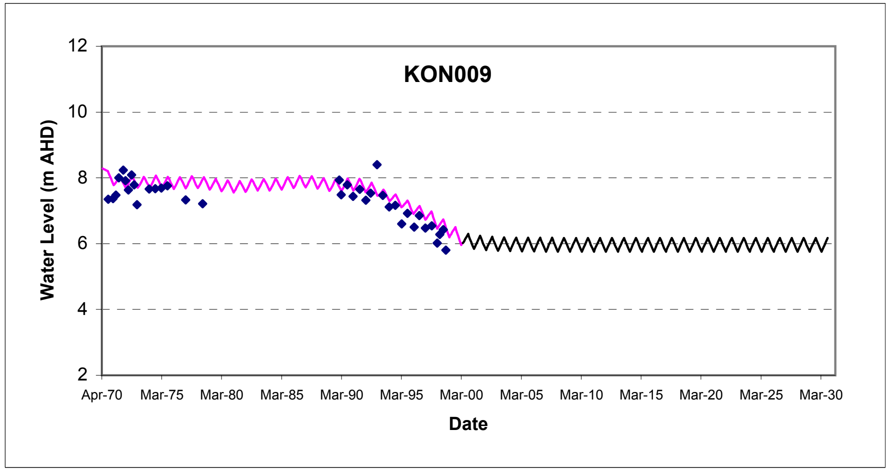
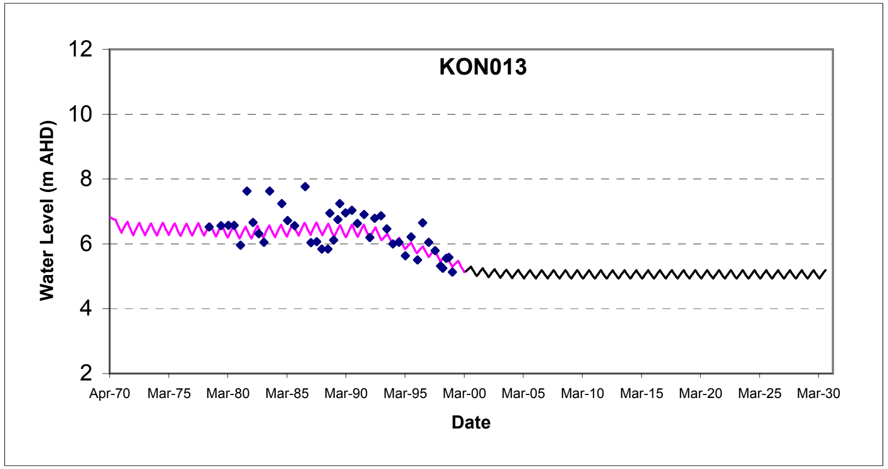
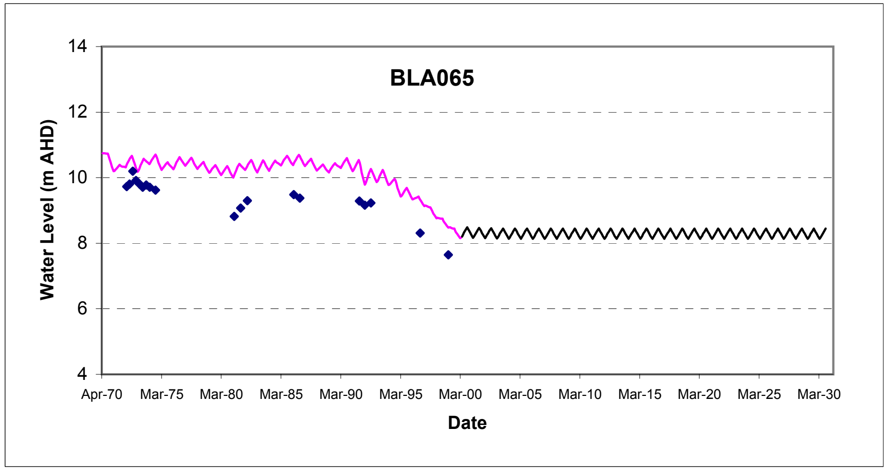


Figure A1-2 *Predicted residual drawdown contours for scenario 1 (2000 to 2030) with no head decline on the northern boundary.*

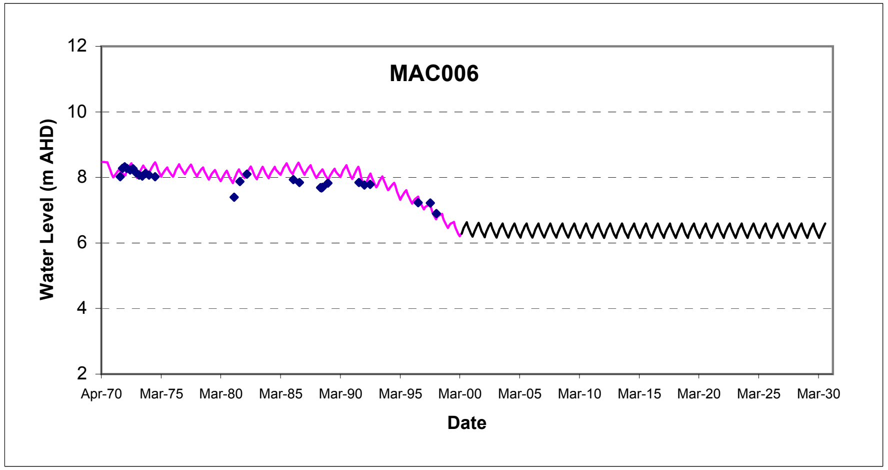


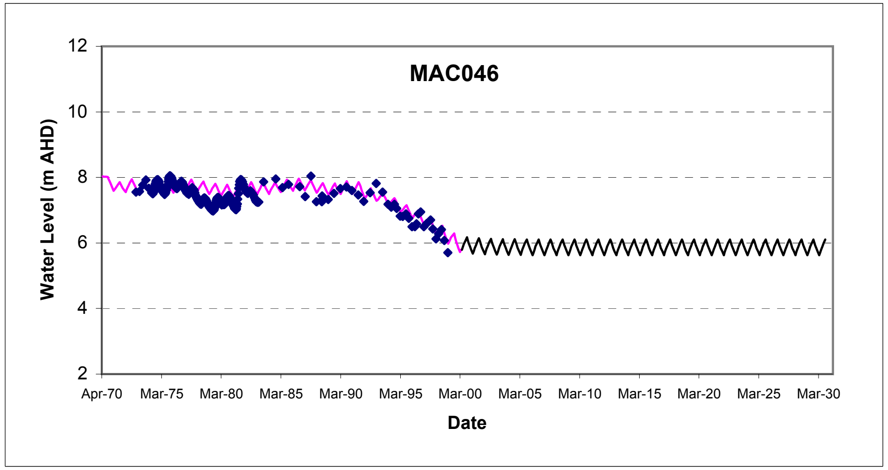


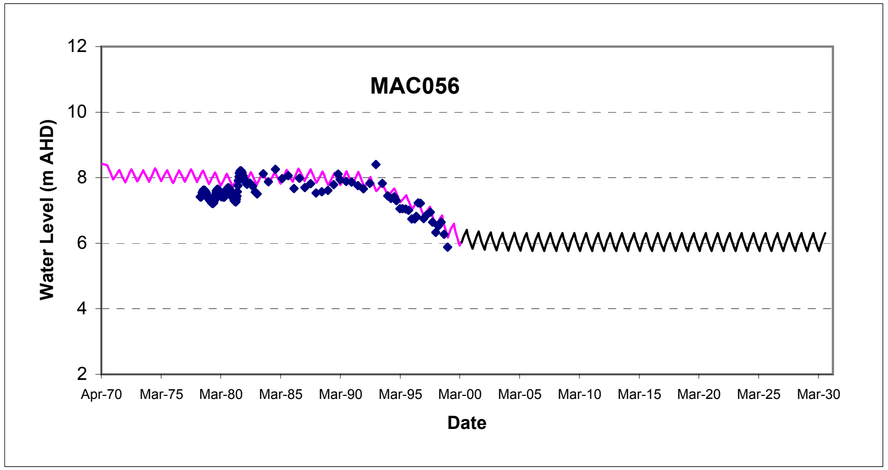


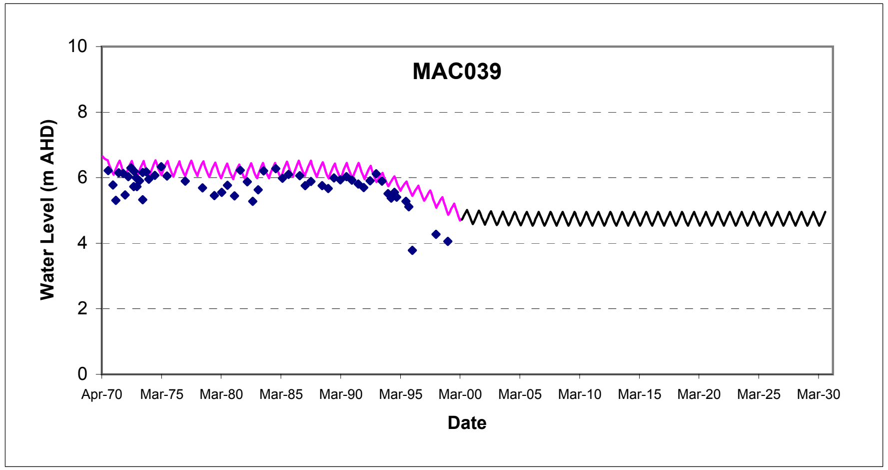


Appendix A1-3 *Hydrographs for Scenario 1 with no head decline on the northern boundary (1970-2030)*

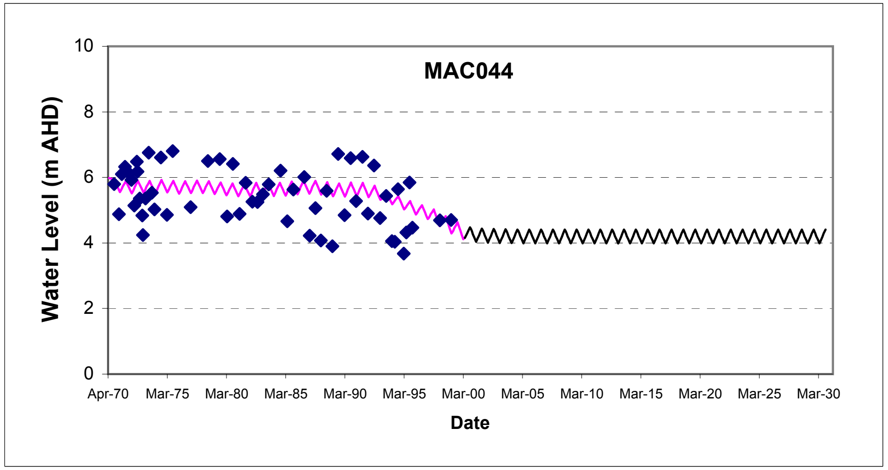


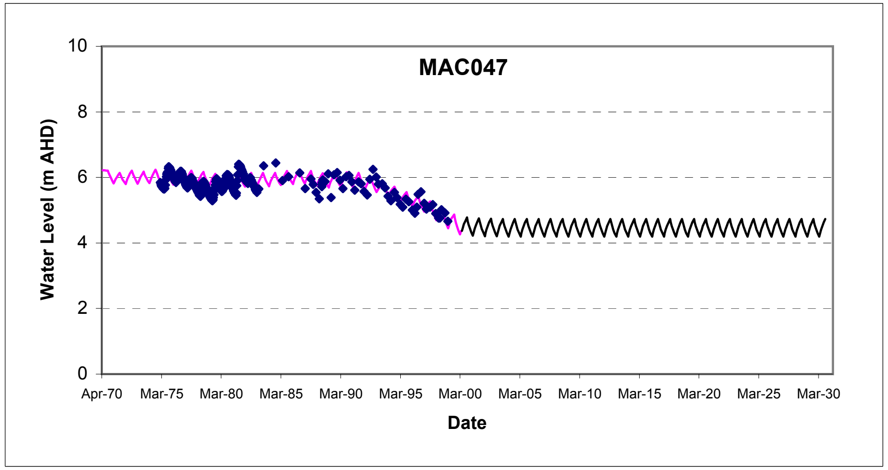


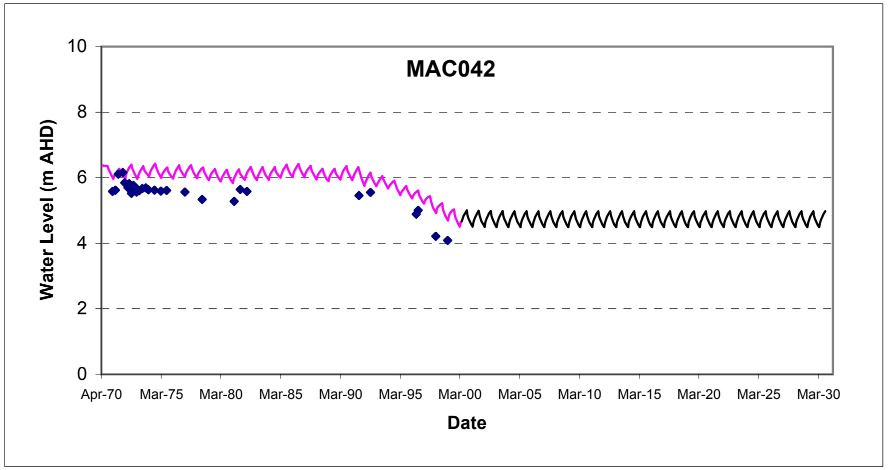


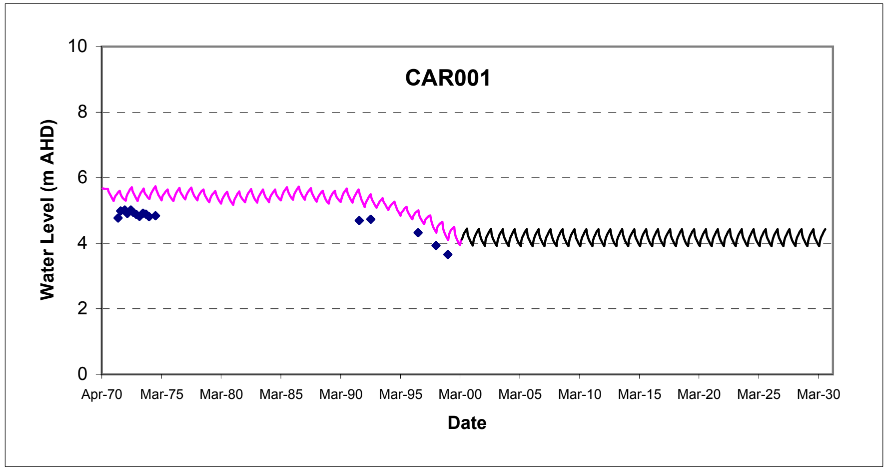


Appendix A1-4 *Hydrographs for Scenario 1 with no head decline on the northern boundary (1970-2030)*

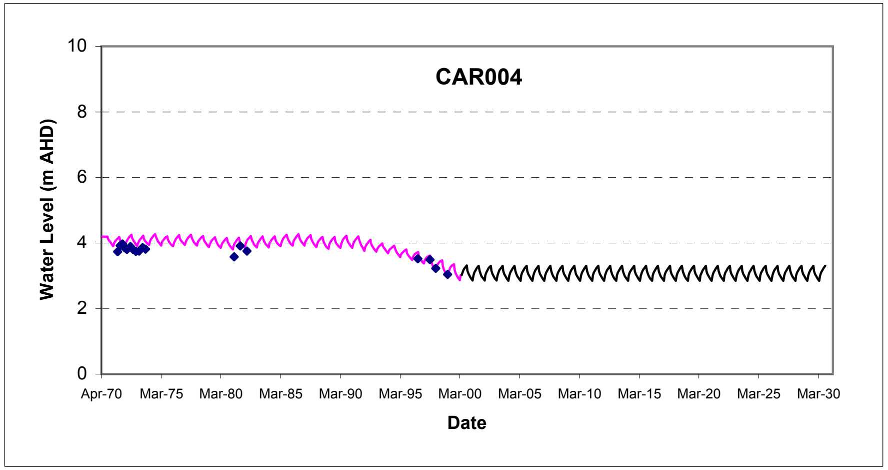


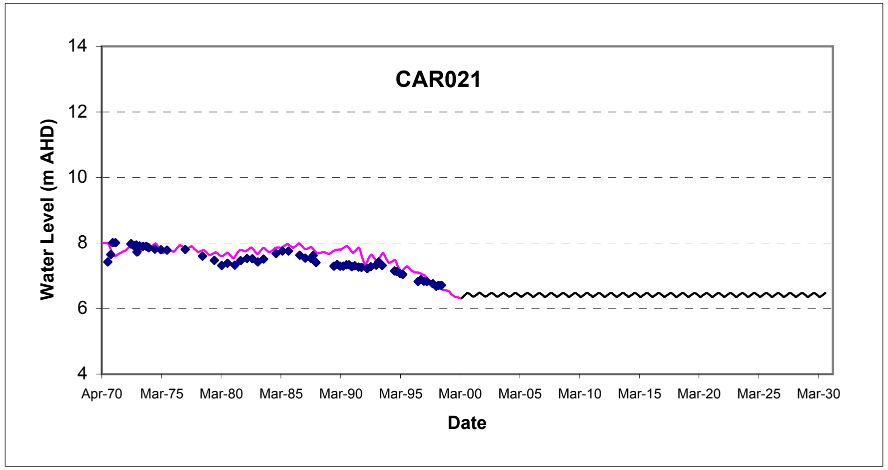


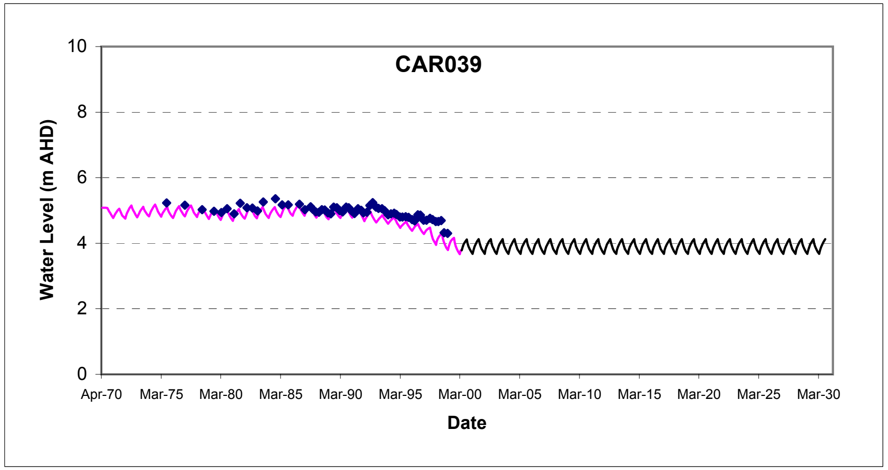


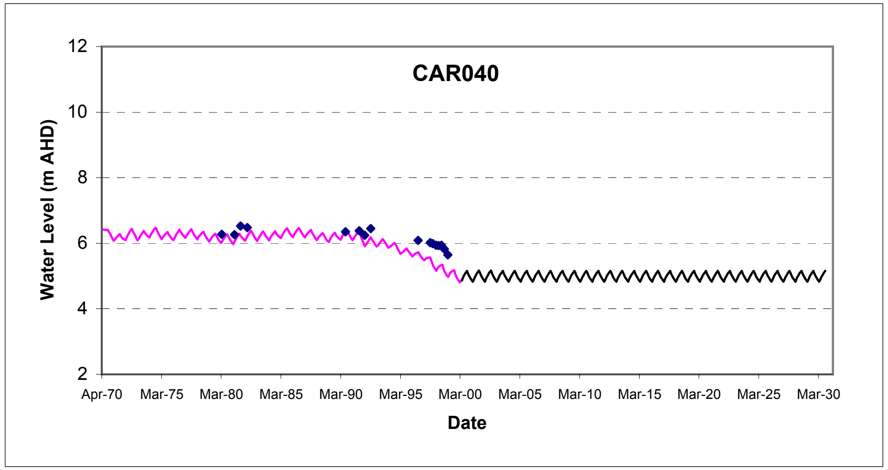


Appendix A1-5 *Hydrographs for Scenario 1 with no head decline on the northern boundary (1970-2030)*









Appendix A1-6 *Hydrographs for Scenario 1 with no head decline on the northern boundary (1970-2030)*

Appendix A2

Scenario 1: Results with a small head decline

on the northern boundary

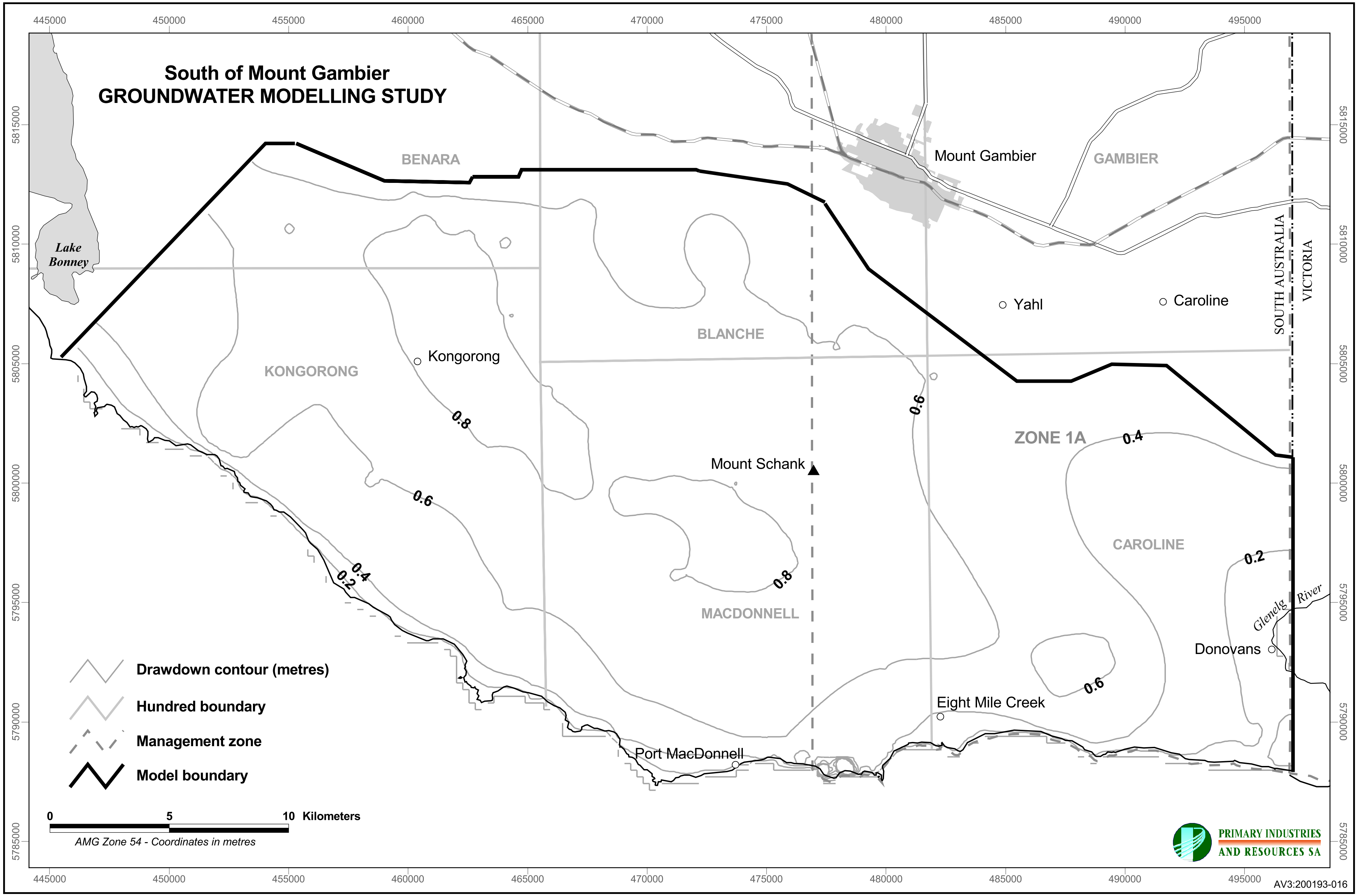


Figure A2-1 *Predicted maximum drawdown contours for scenario 1 (2000 to 2030) with small head decline on the northern boundary.*

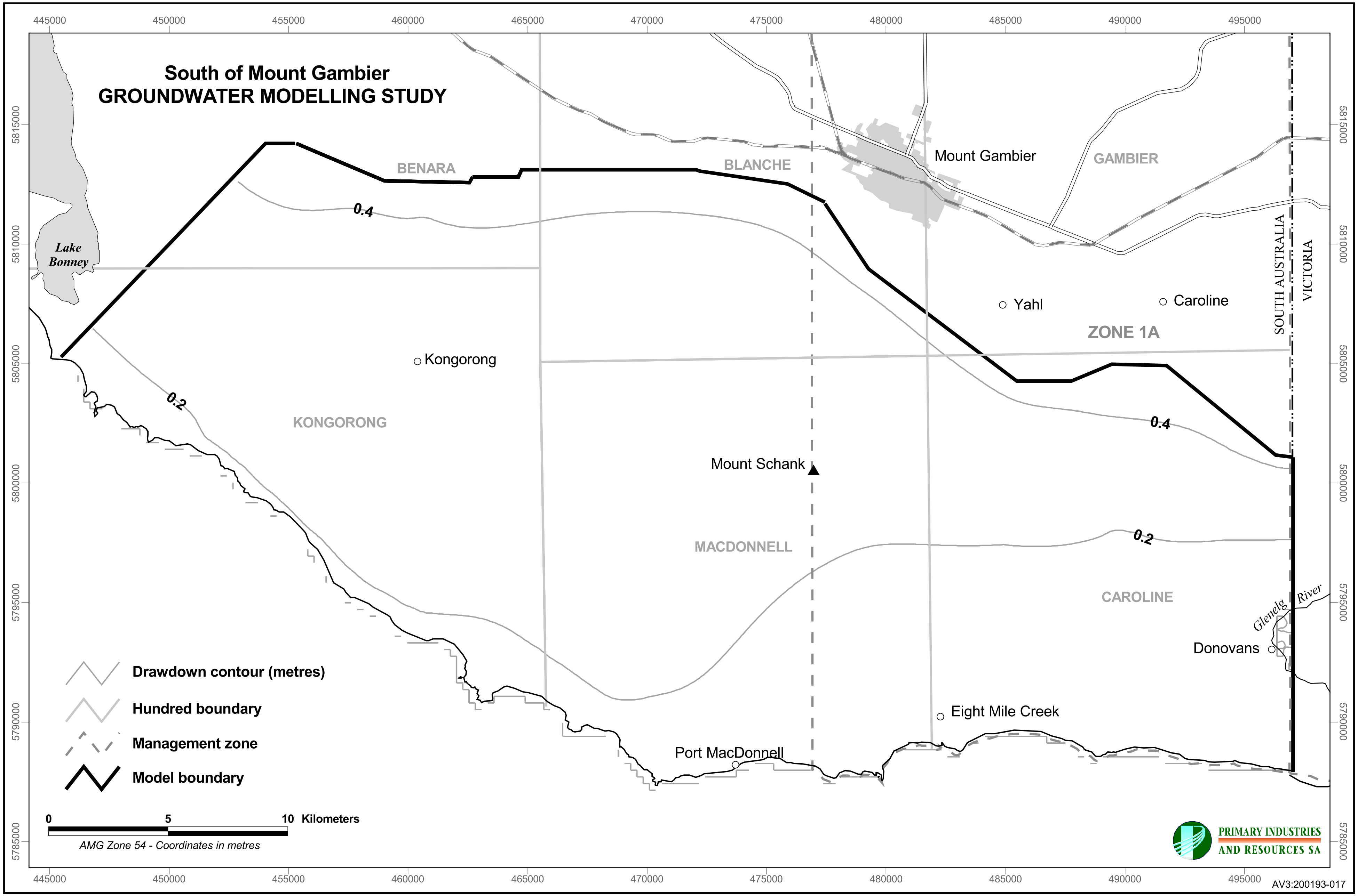
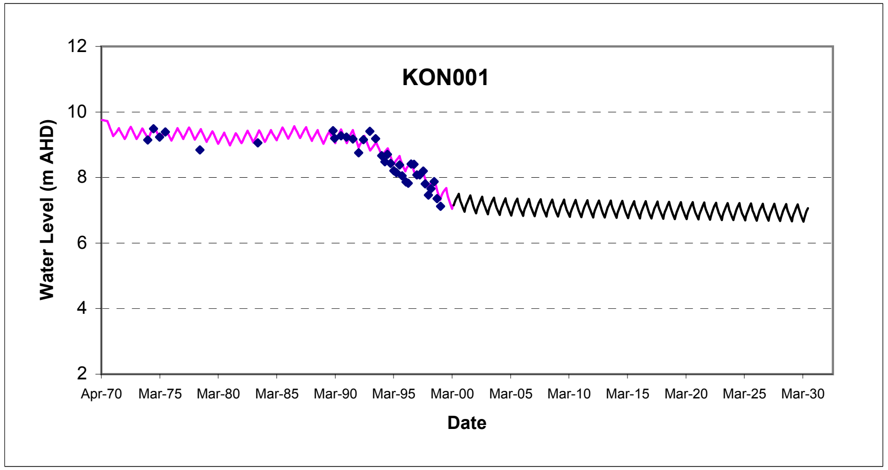
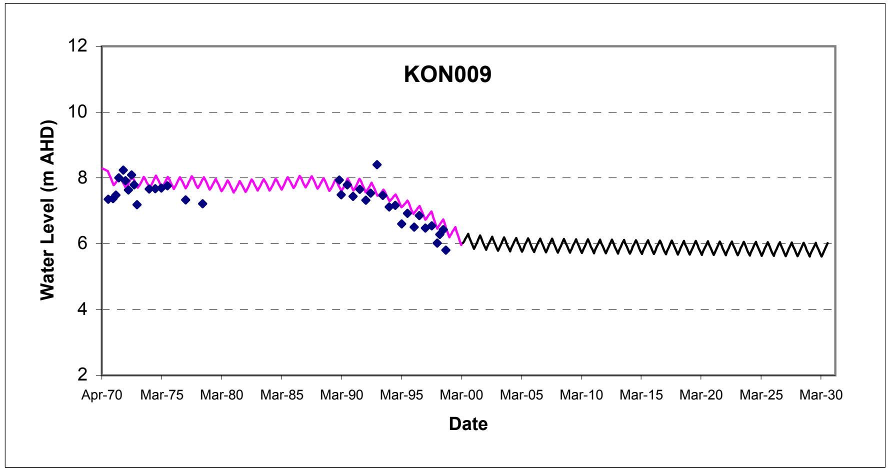
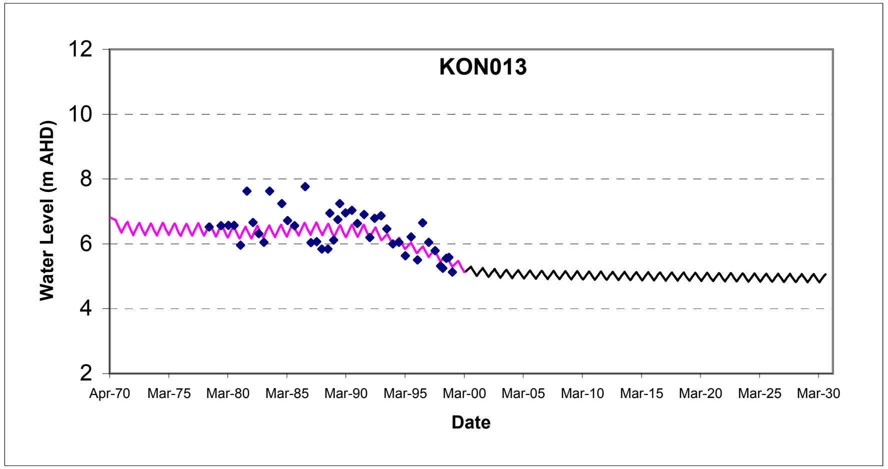
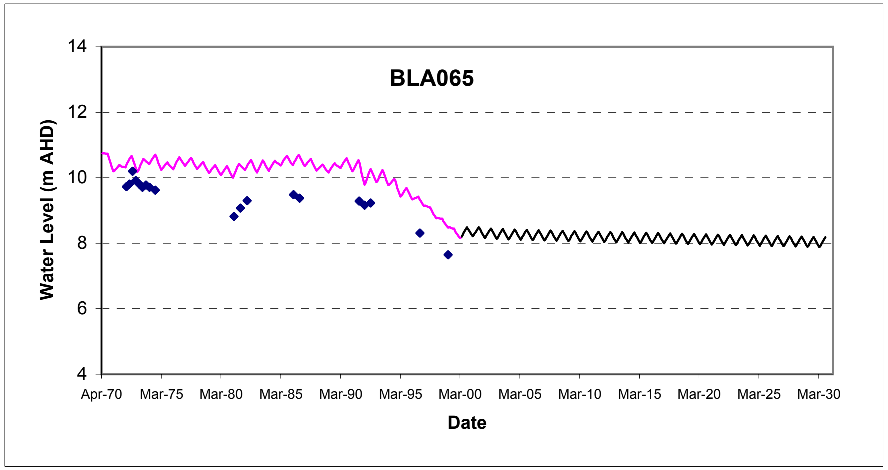


Figure A2-2 *Predicted residual drawdown contours for scenario 1 (2000 to 2030) with small head decline on the northern boundary.*

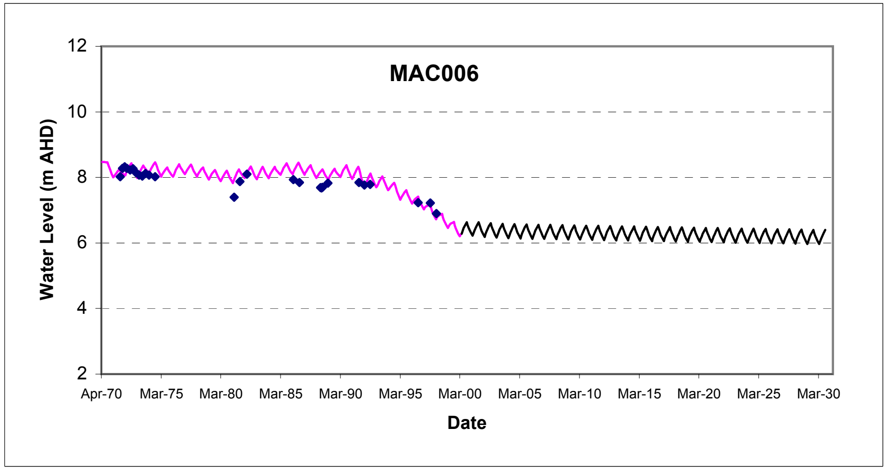


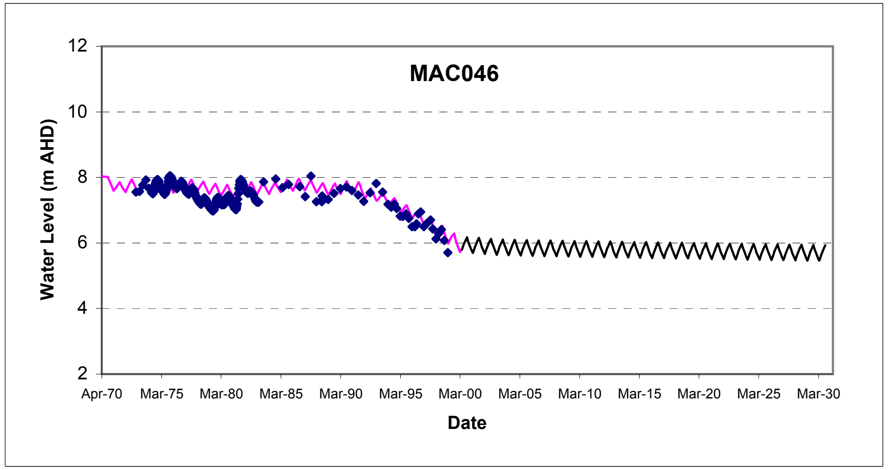


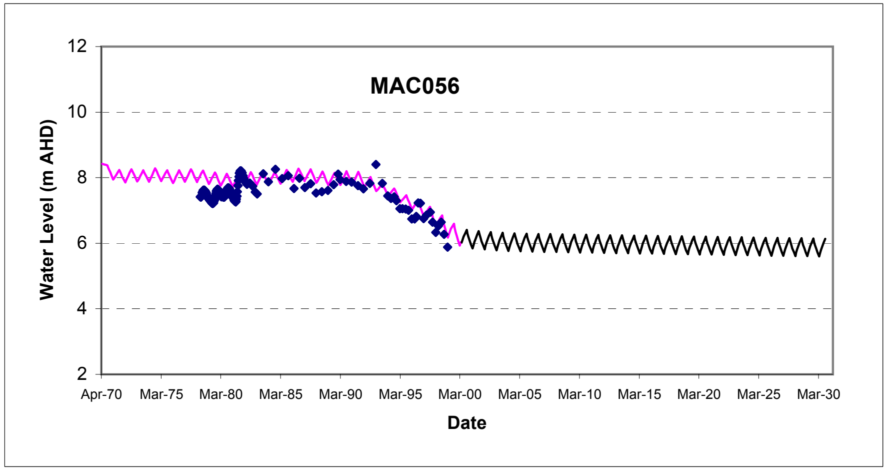


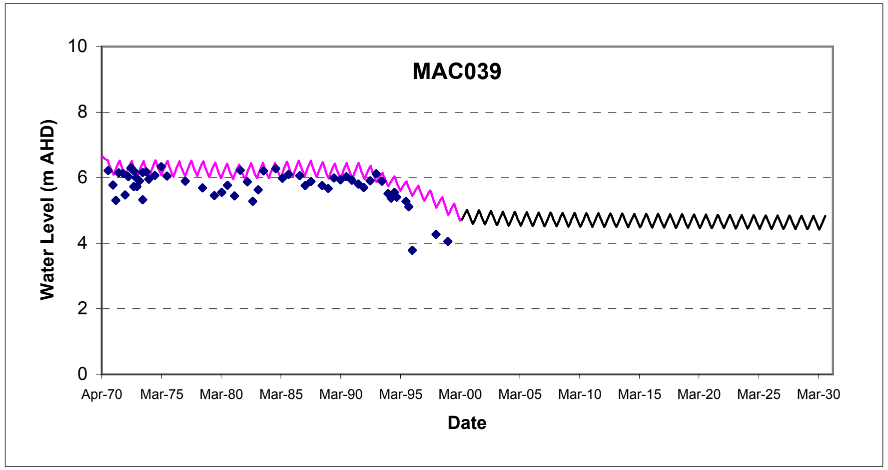


Appendix A2-3 *Hydrographs for Scenario 1 with small head decline on the northern boundary (1970-2030)*

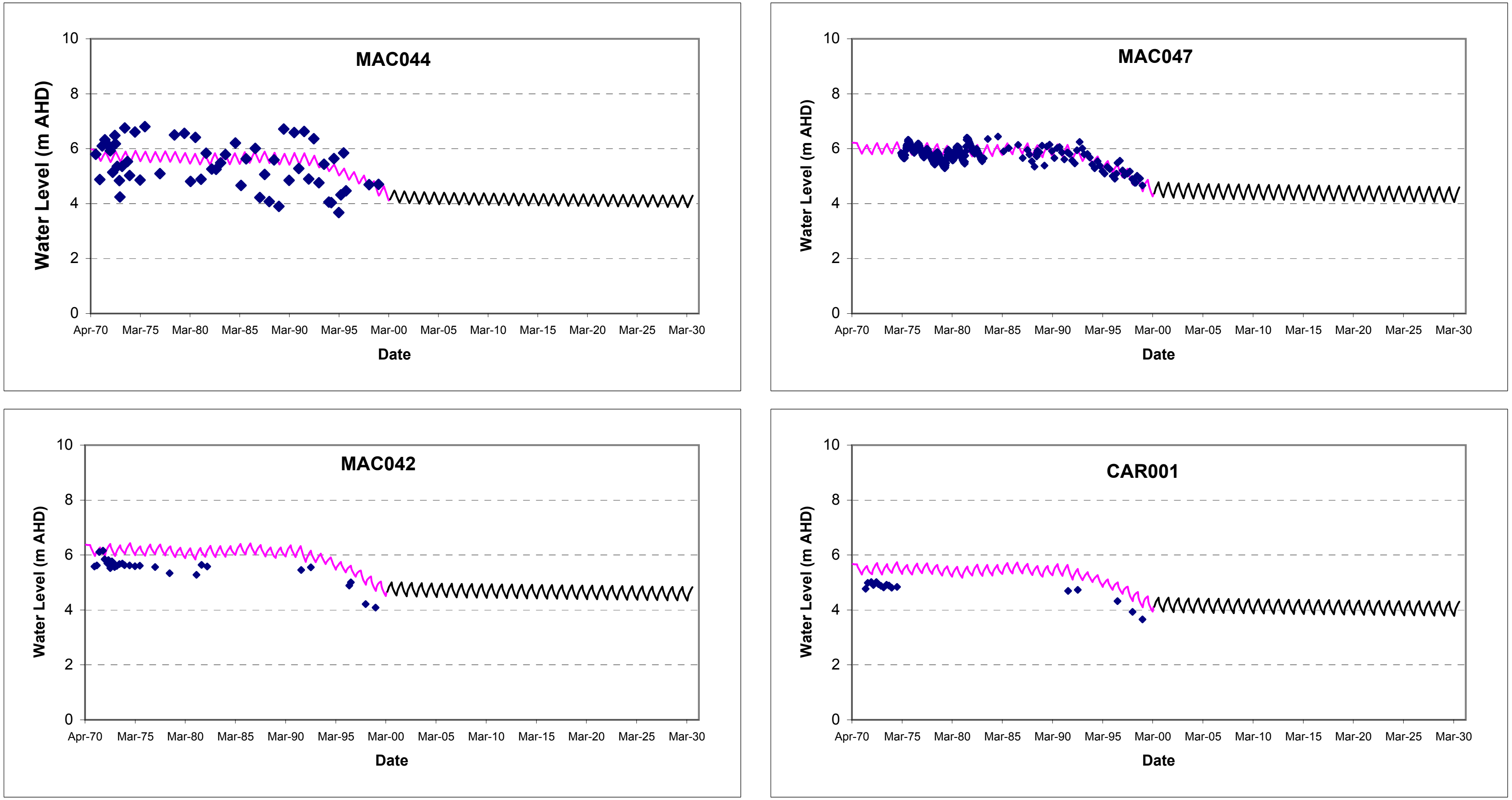




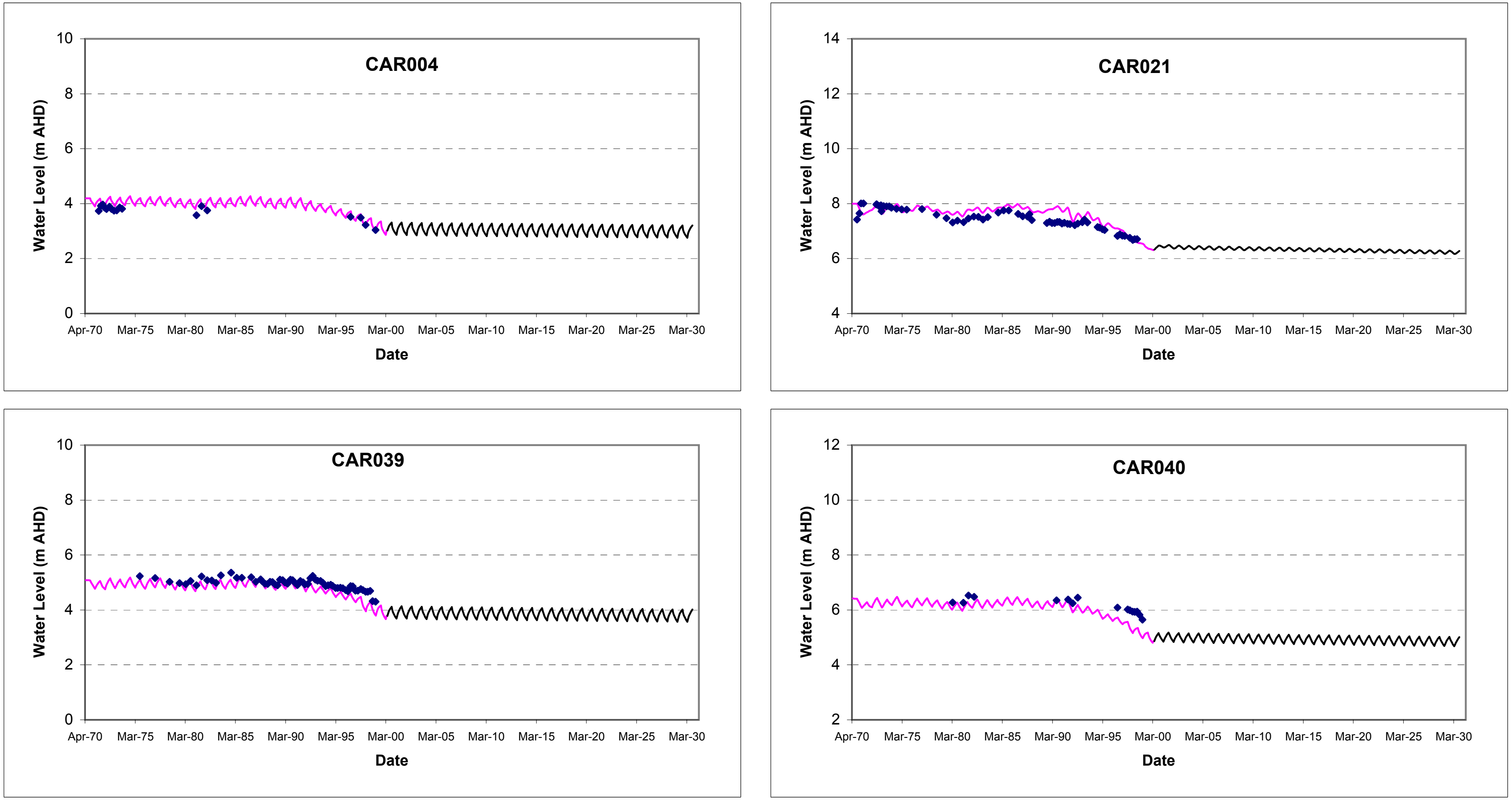




Appendix A2-4 *Hydrographs for Scenario 1 with small head decline on the northern boundary (1970-2030)*



Appendix A2-5 *Hydrographs for Scenario 1 with small head decline on the northern boundary (1970-2030)*



Appendix A2-6 *Hydrographs for Scenario 1 with small head decline on the northern boundary (1970-2030)*

Appendix A3

Scenario 1: Results with a large head decline

on the northern boundary

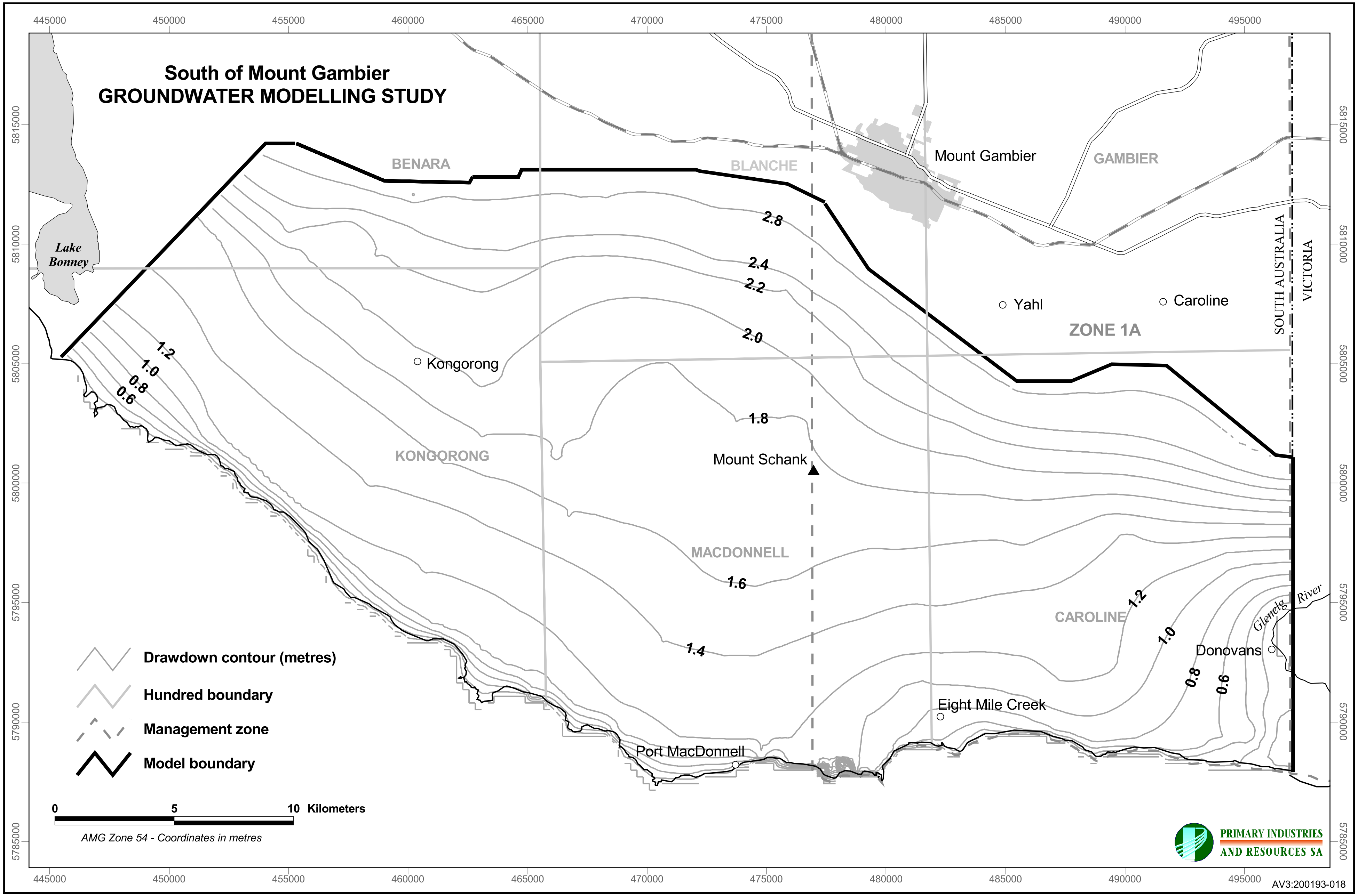


Figure A3-1 *Predicted maximum drawdown contours for scenario 1 (2000 to 2030) with large head decline on the northern boundary.*

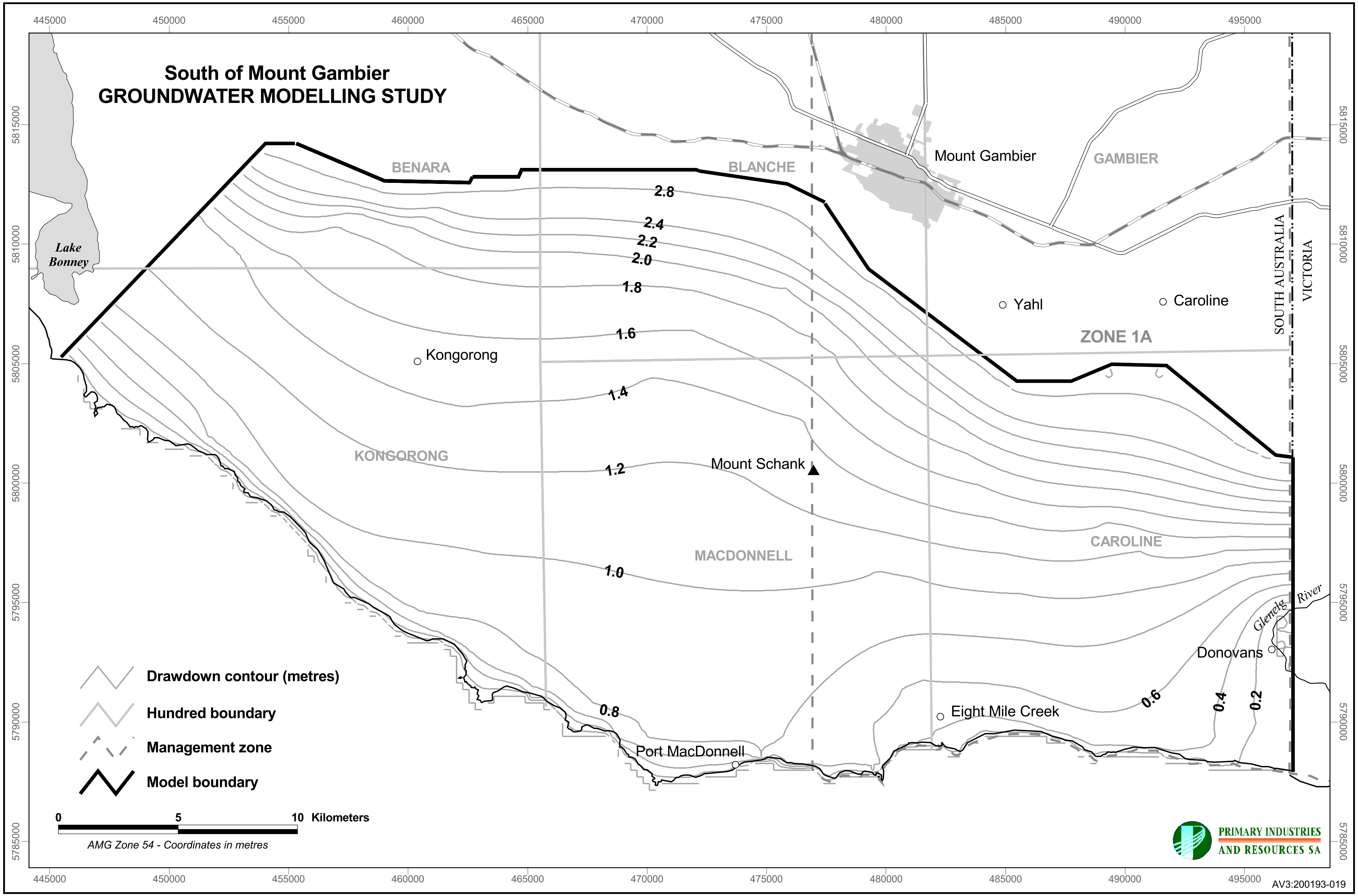
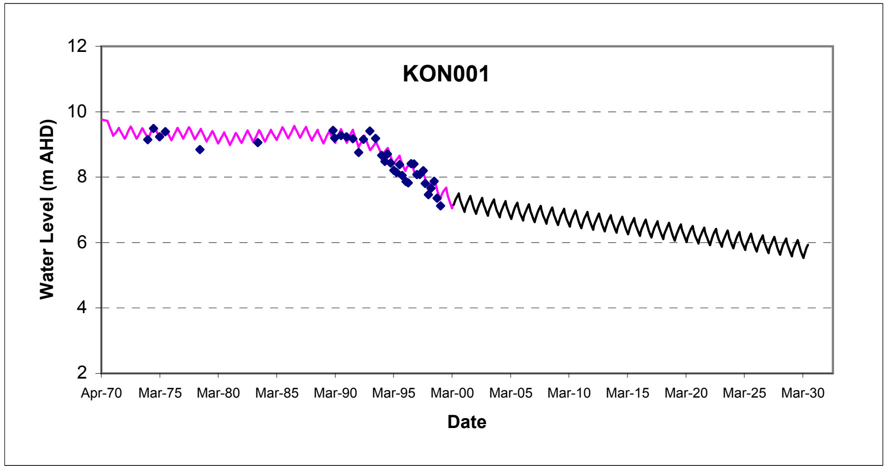
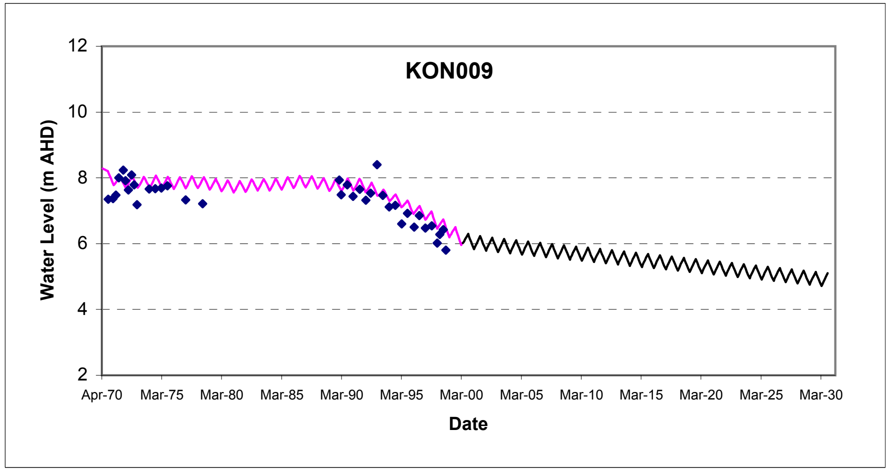
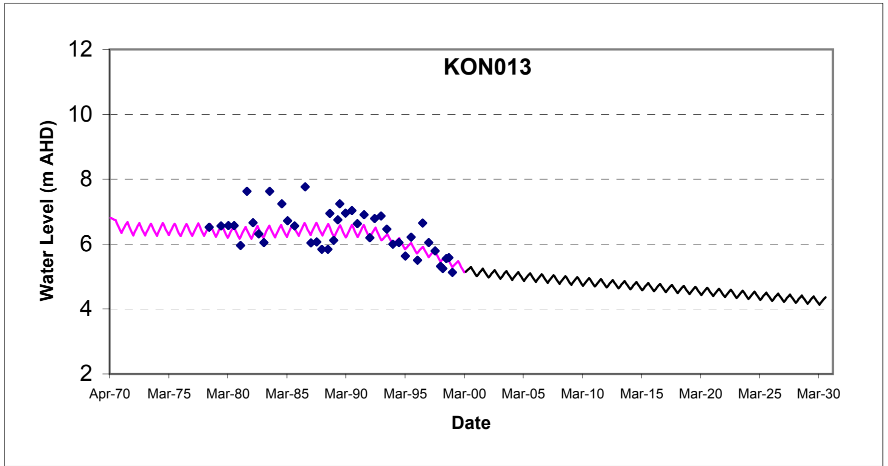
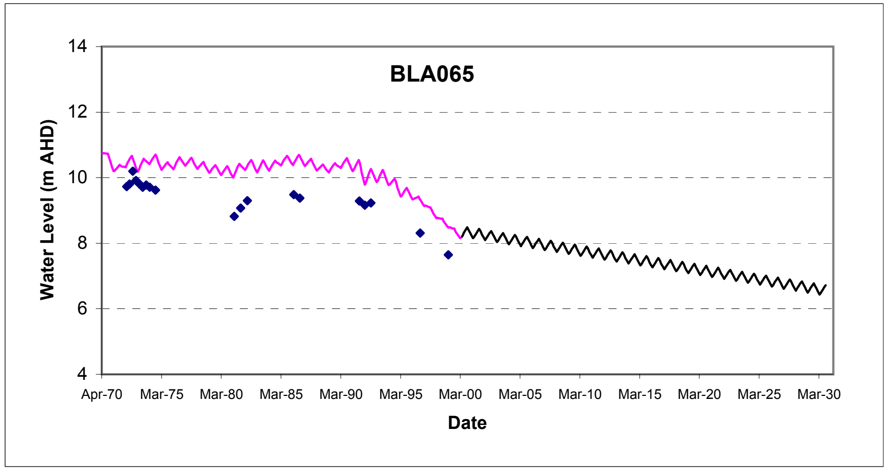


Figure A3-2 *Predicted residual drawdown contours for scenario 1 (2000 to 2030) with large head decline on the northern boundary.*

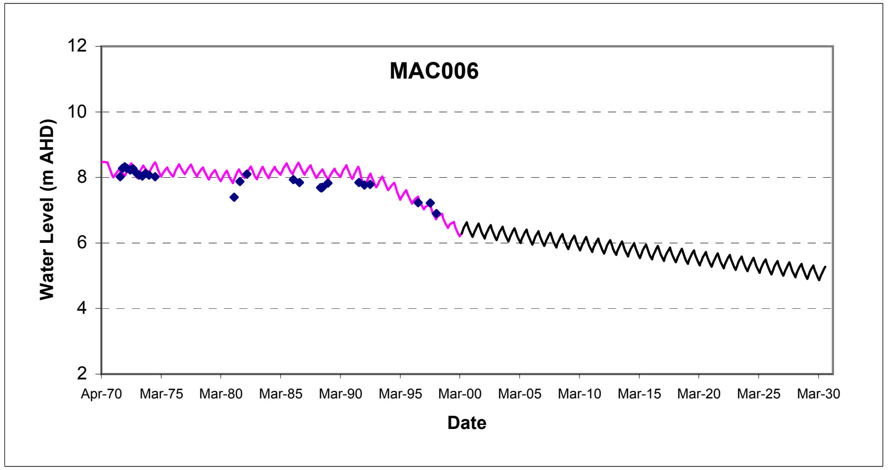


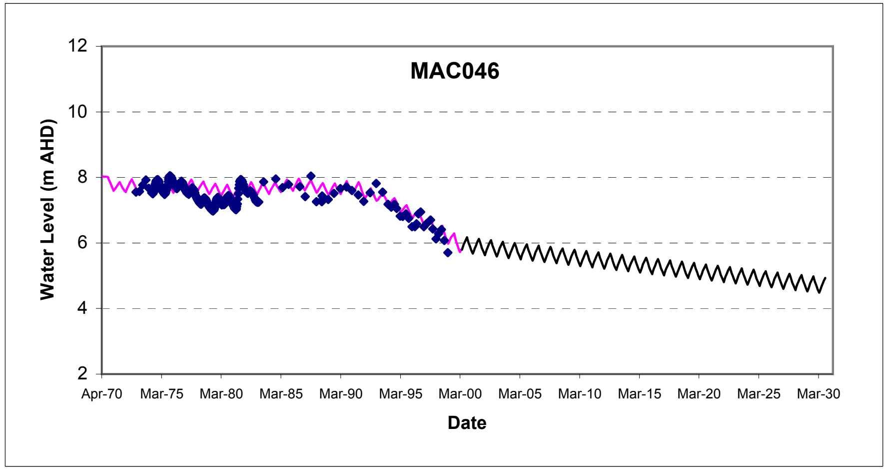


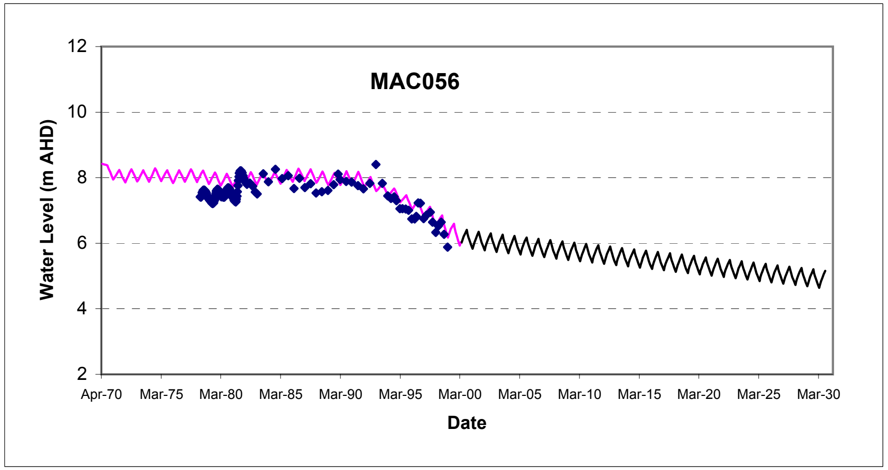


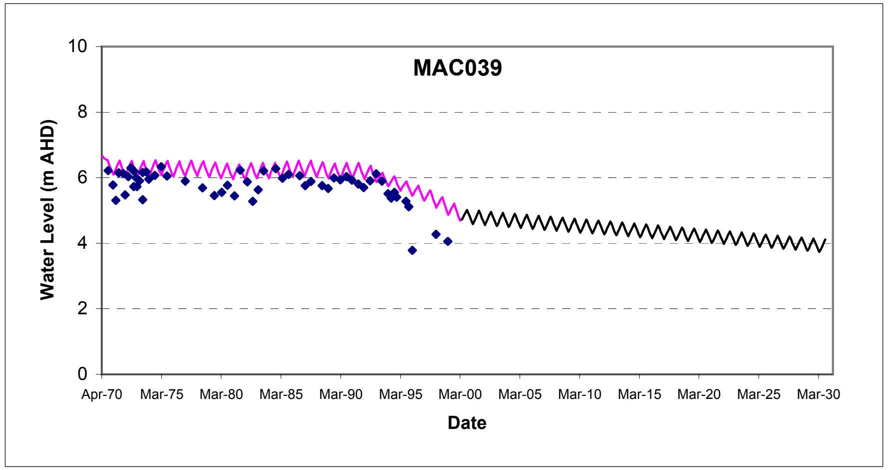


Appendix A3-3 *Hydrographs for Scenario 1 with large head decline on the northern boundary (1970-2030)*

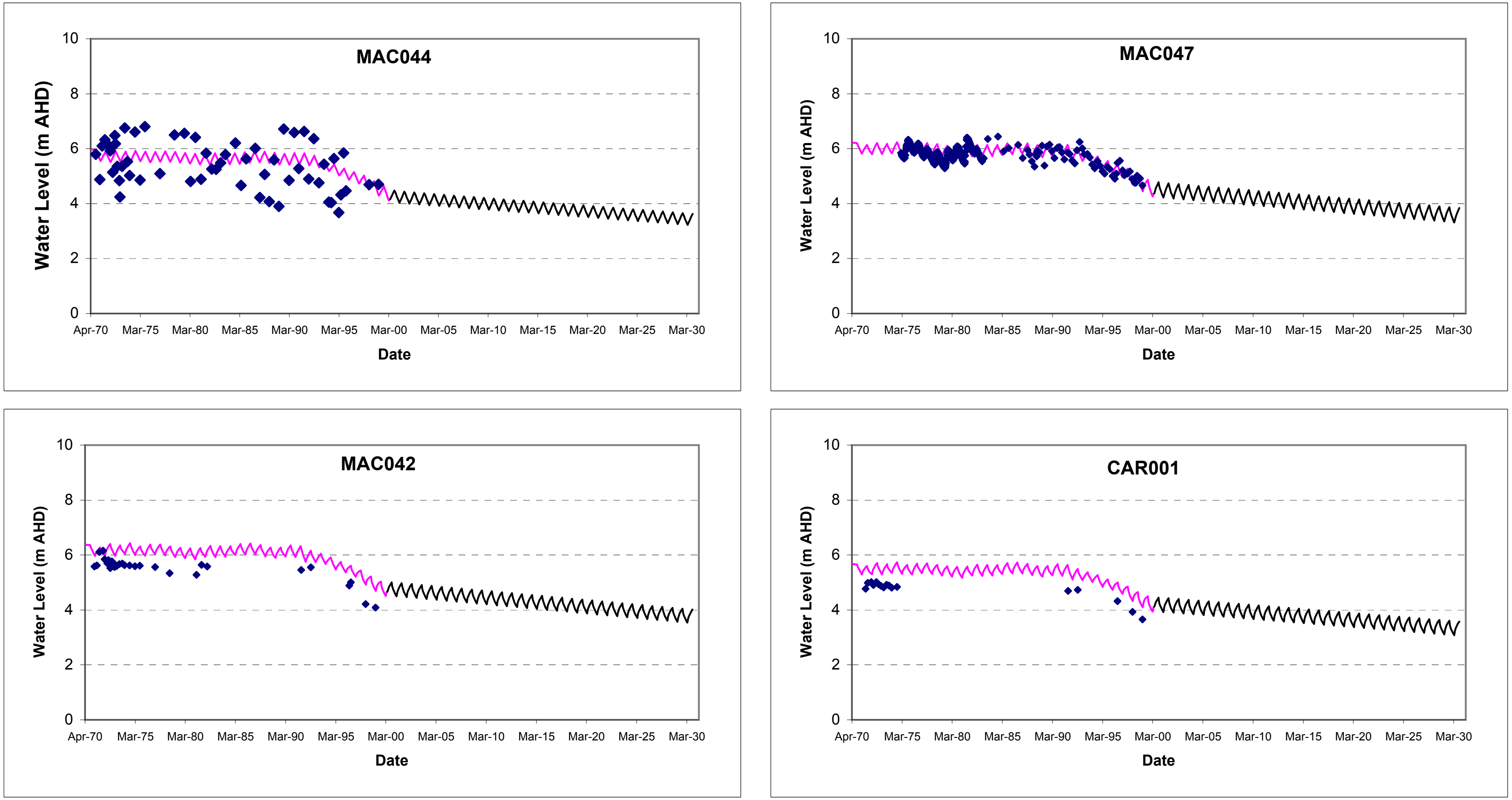




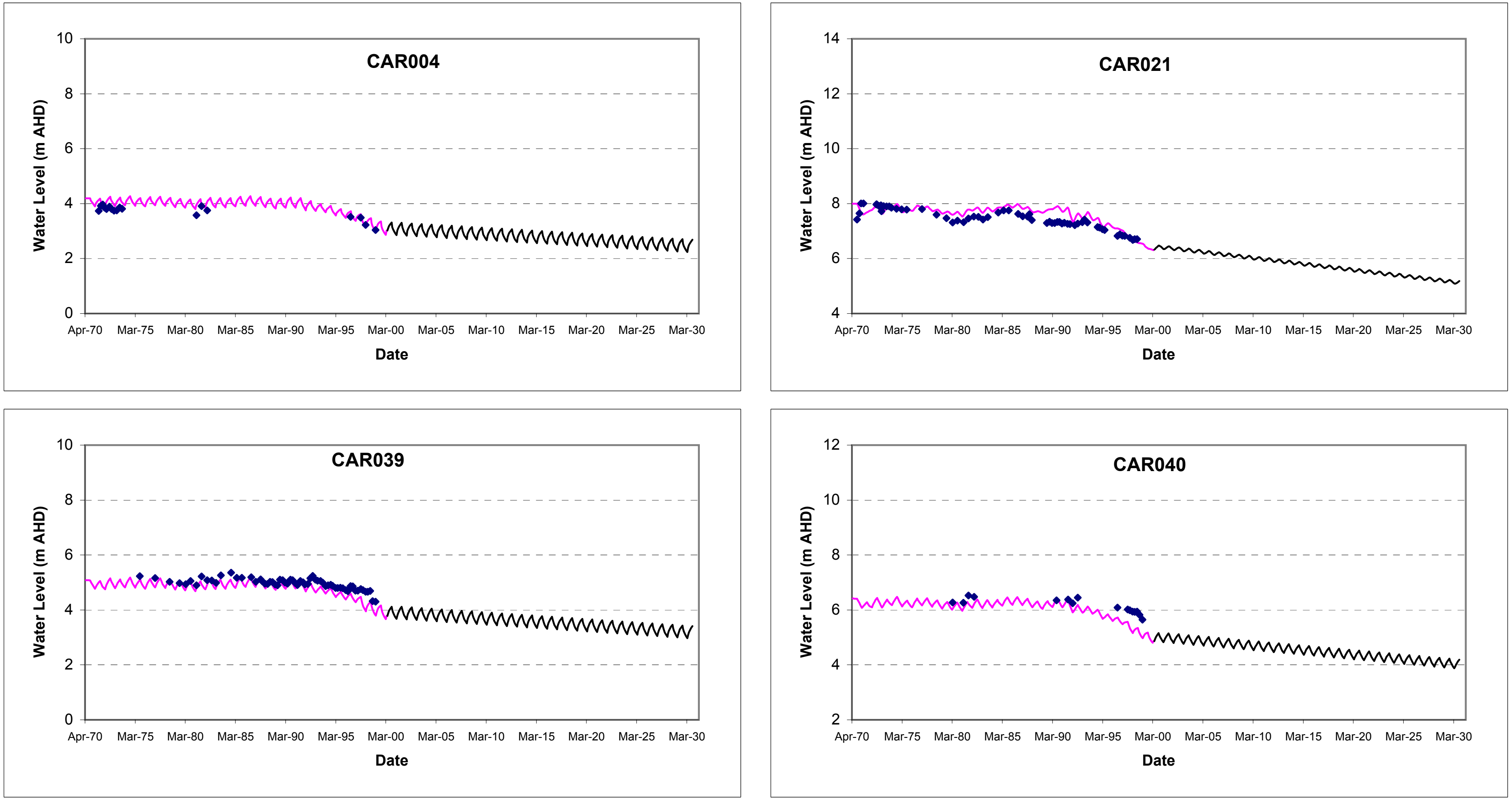




Appendix A3-4 *Hydrographs for Scenario 1 with large head decline on the northern boundary (1970-2030)*



Appendix A3-5 *Hydrographs for Scenario 1 with large head decline on the northern boundary (1970-2030)*



Appendix A3-6 *Hydrographs for Scenario 1 with large head decline on the northern boundary (1970-2030)*

Appendix B1

Scenario 2: Results with no head decline

on the northern boundary

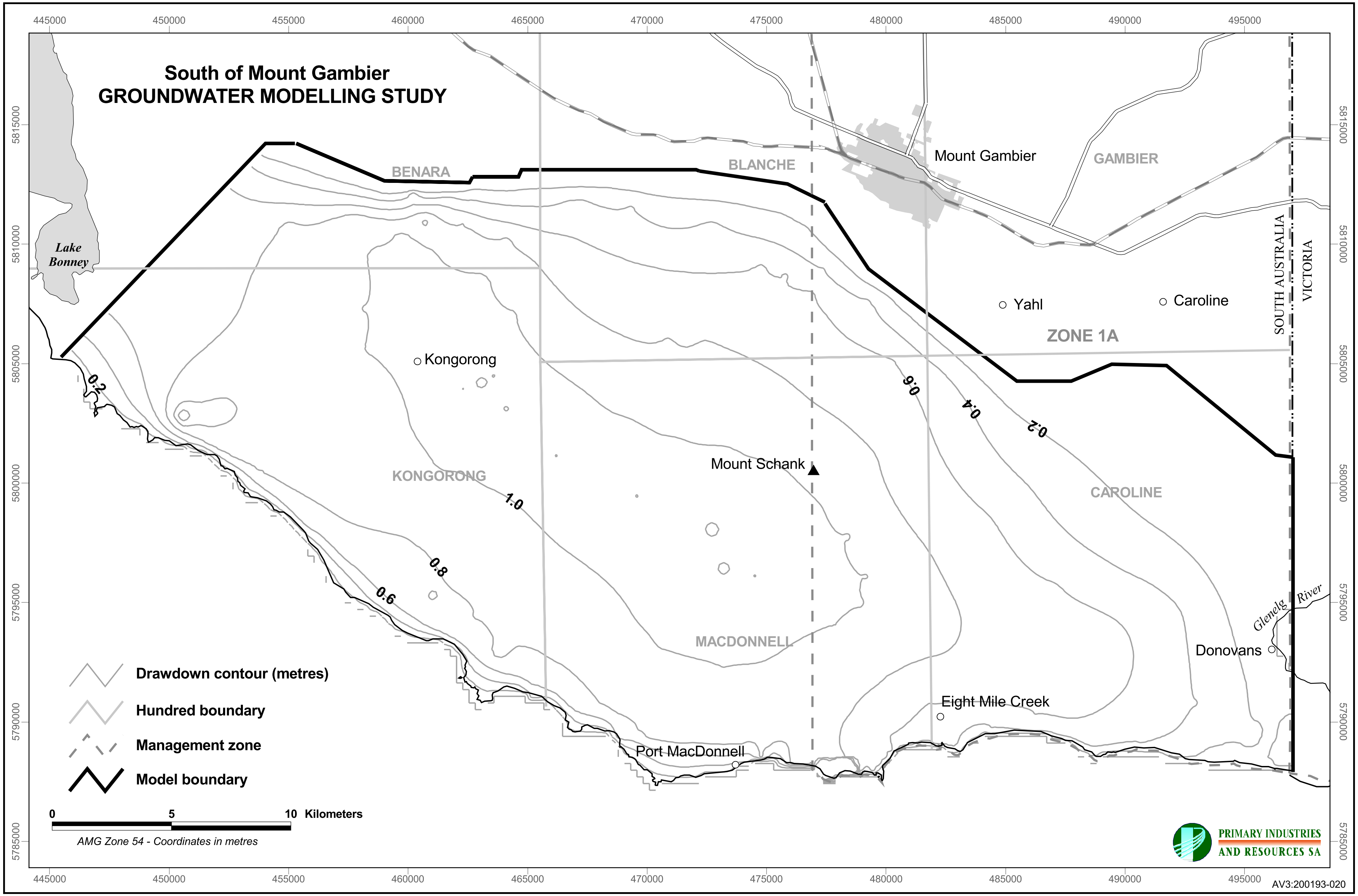


Figure B1-1 *Predicted maximum drawdown contours for scenario 2 (2000 to 2030) with no head decline on the northern boundary.*

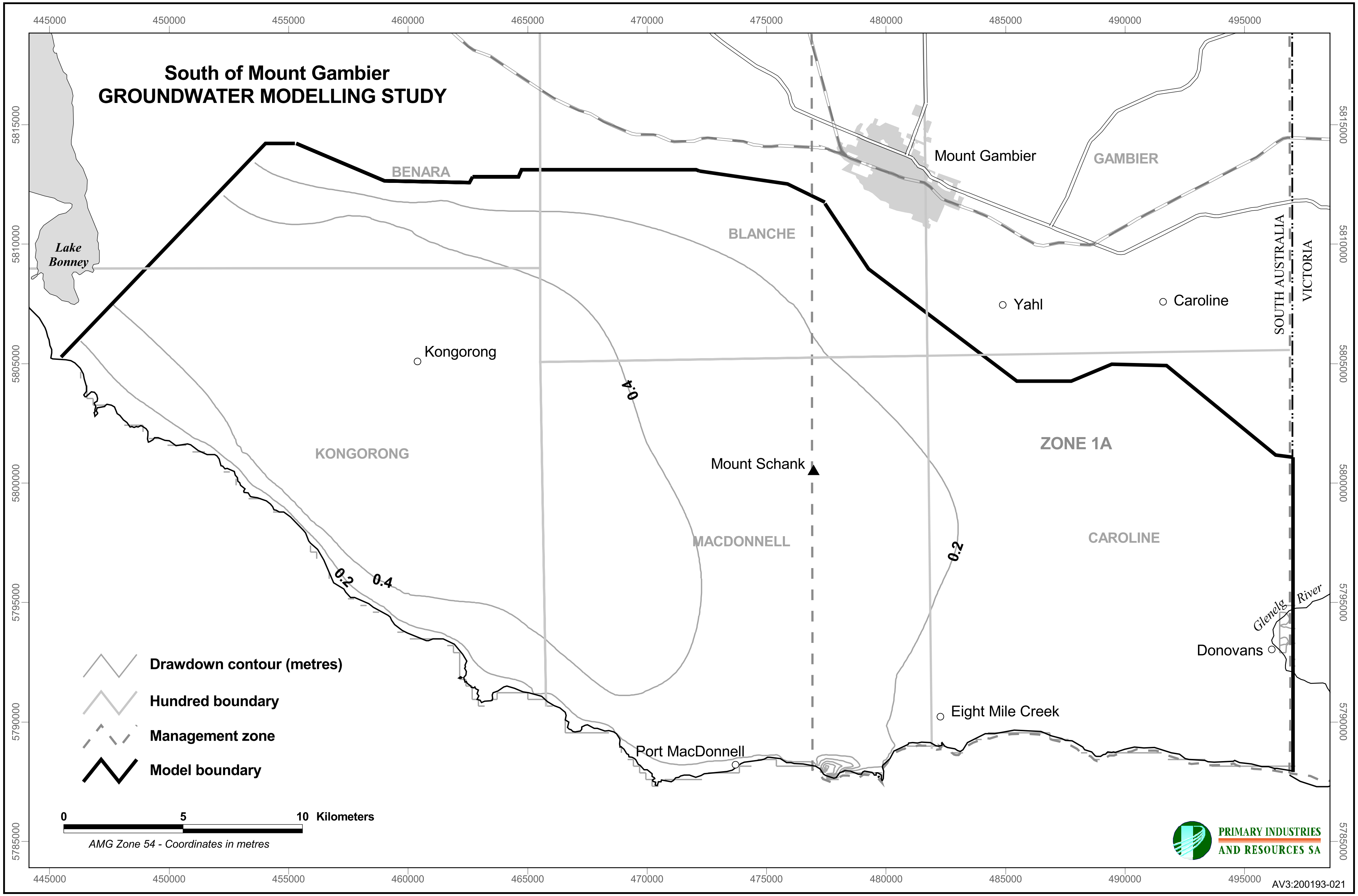
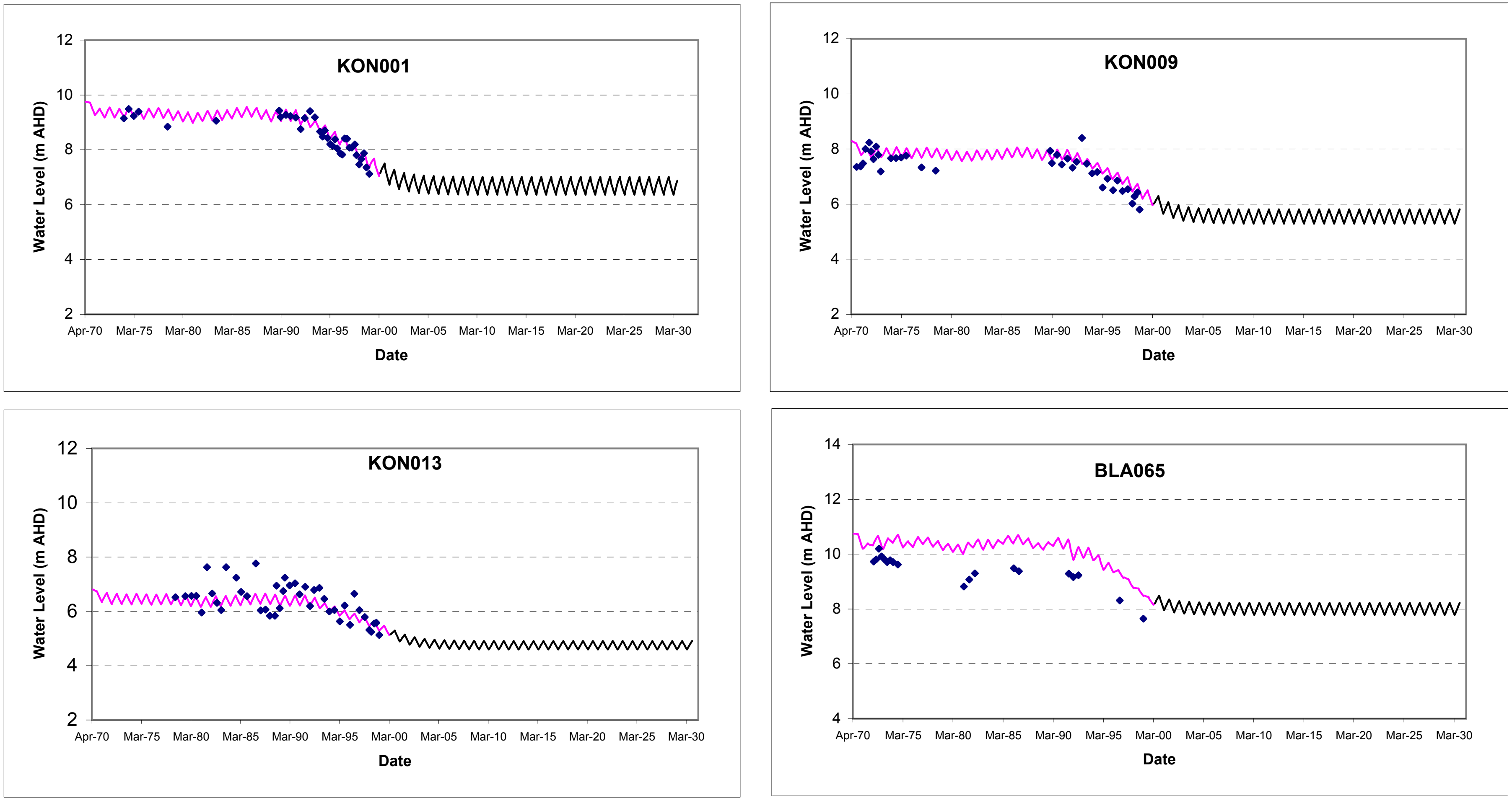
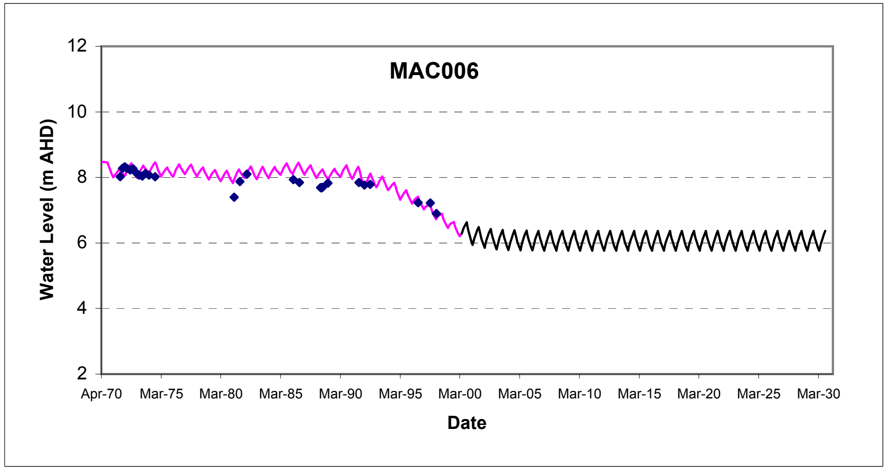
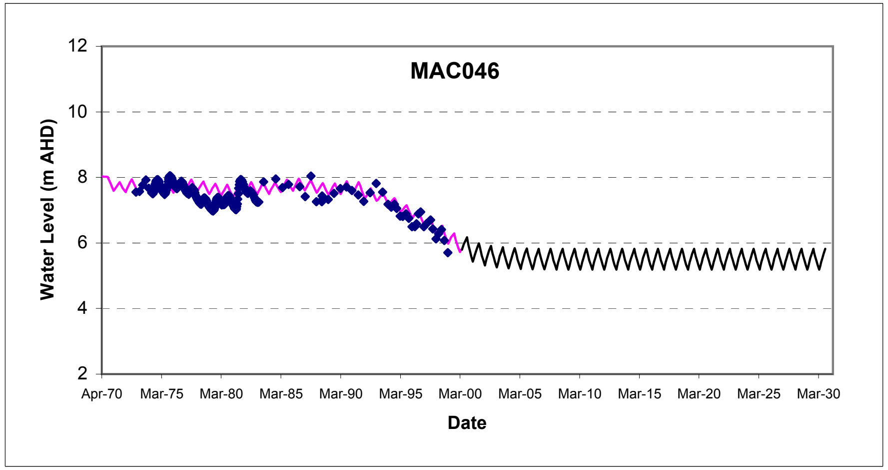


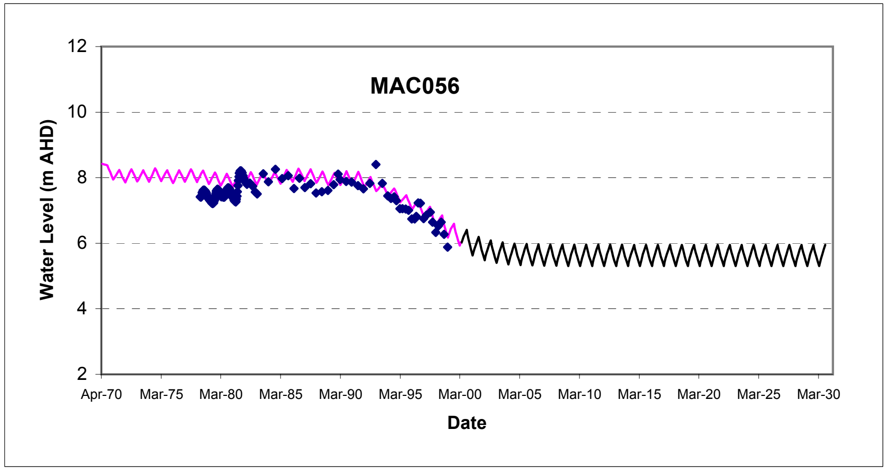
Figure B1-2 *Predicted residual drawdown contours for scenario 2 (2000 to 2030) with no head decline on the northern boundary.*

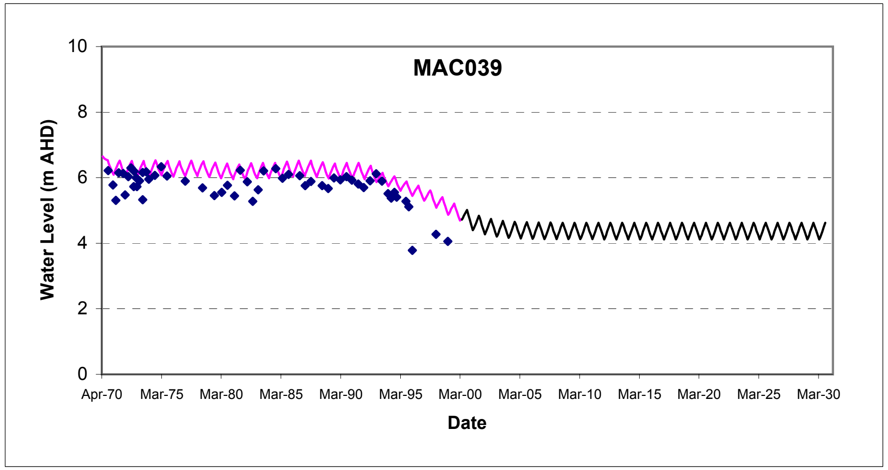


Appendix B1-3 *Hydrographs for Scenario 2 with no head decline on the northern boundary (1970-2030)*

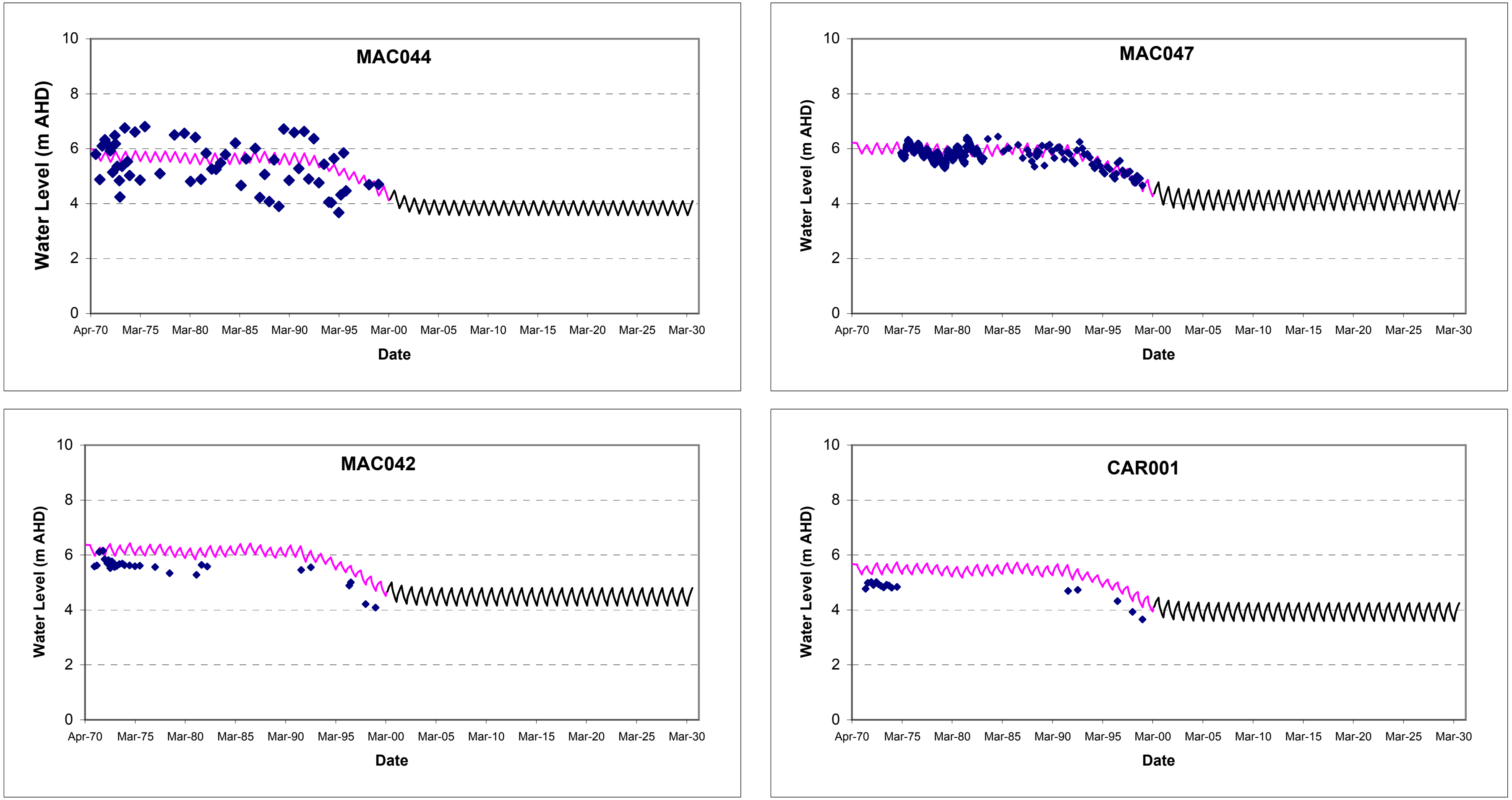




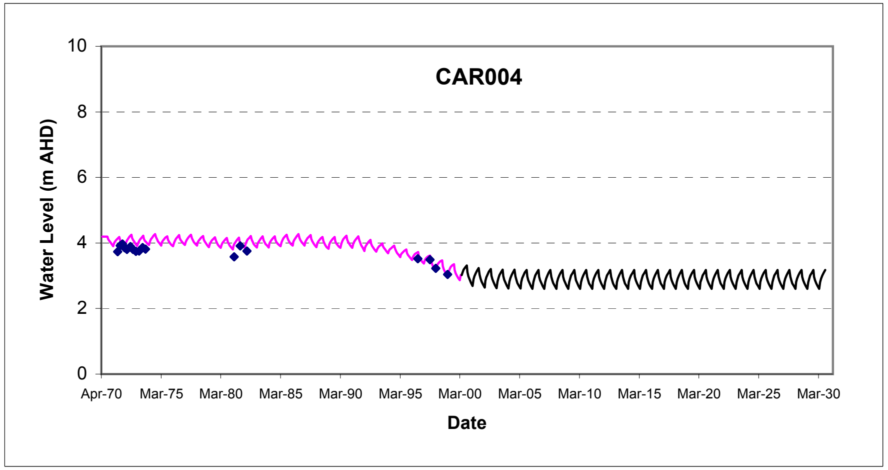


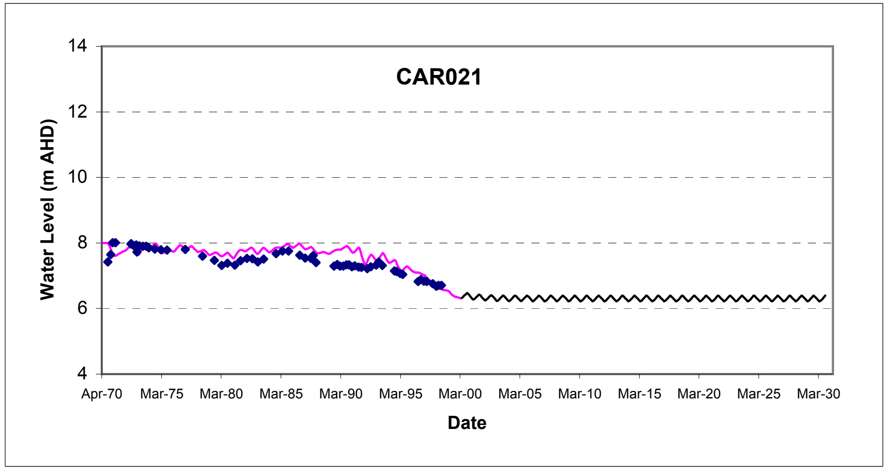


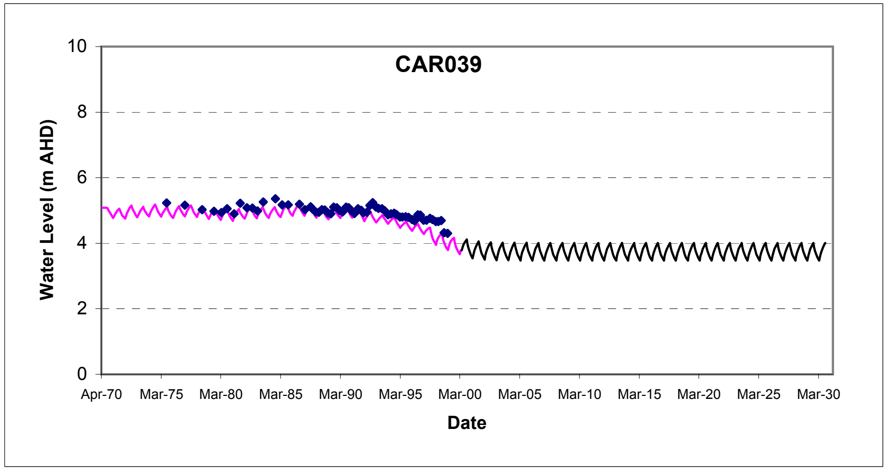
Appendix B1-4 *Hydrographs for Scenario 2 with no head decline on the northern boundary (1970-2030)*

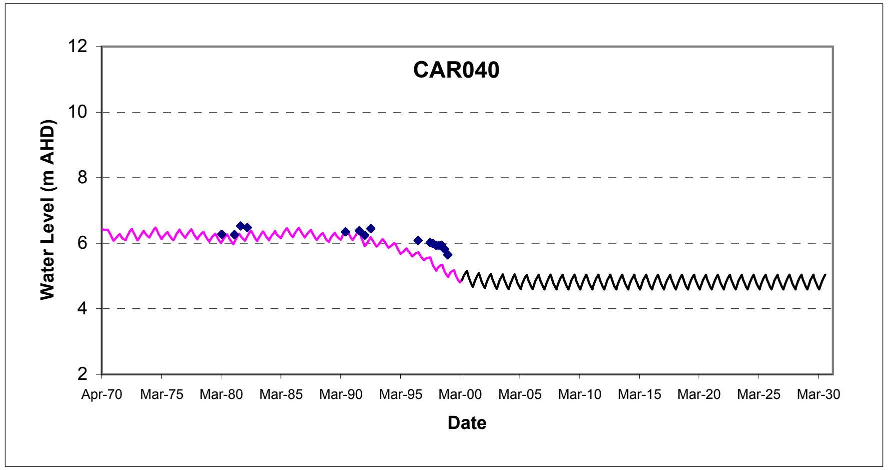


Appendix B1-5 *Hydrographs for Scenario 2 with no head decline on the northern boundary (1970-2030)*









Appendix B1-6 *Hydrographs for Scenario 2 with no head decline on the northern boundary (1970-2030)*

Appendix B2

Scenario 2: Results with a small head decline

on the northern boundary

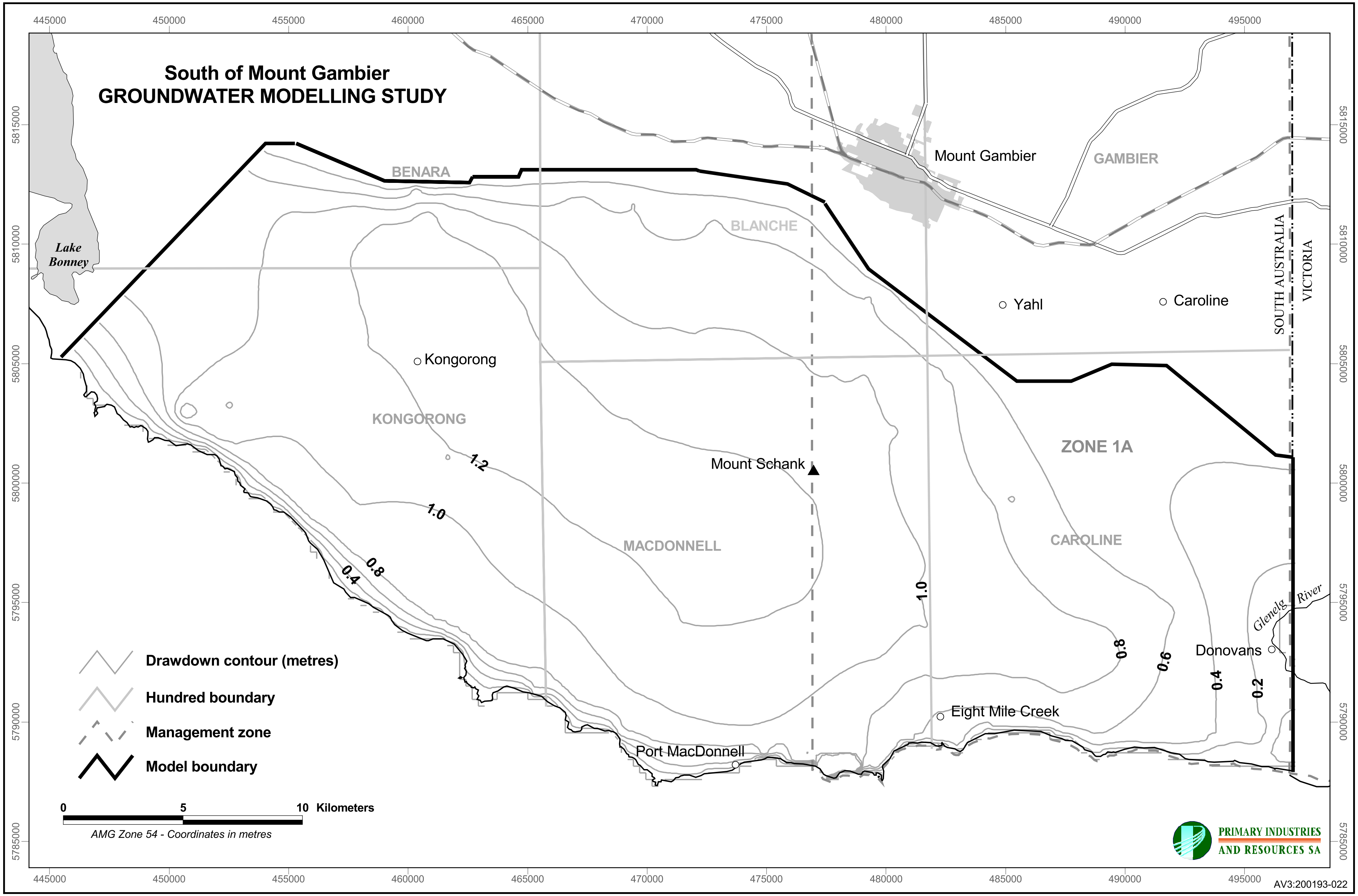


Figure B2-1 *Predicted maximum drawdown contours for scenario 2 (2000 to 2030) with small head decline on the northern boundary.*

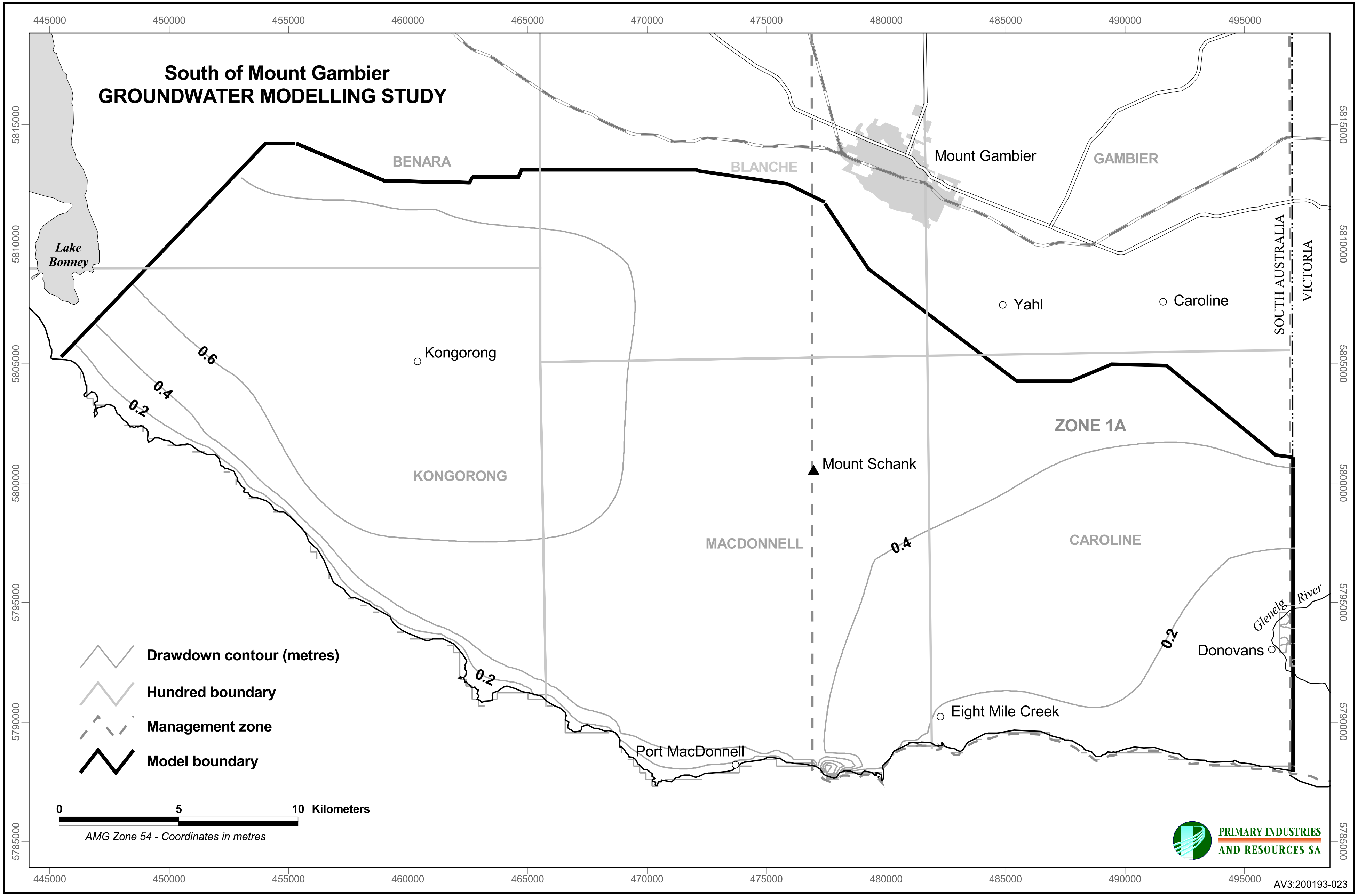
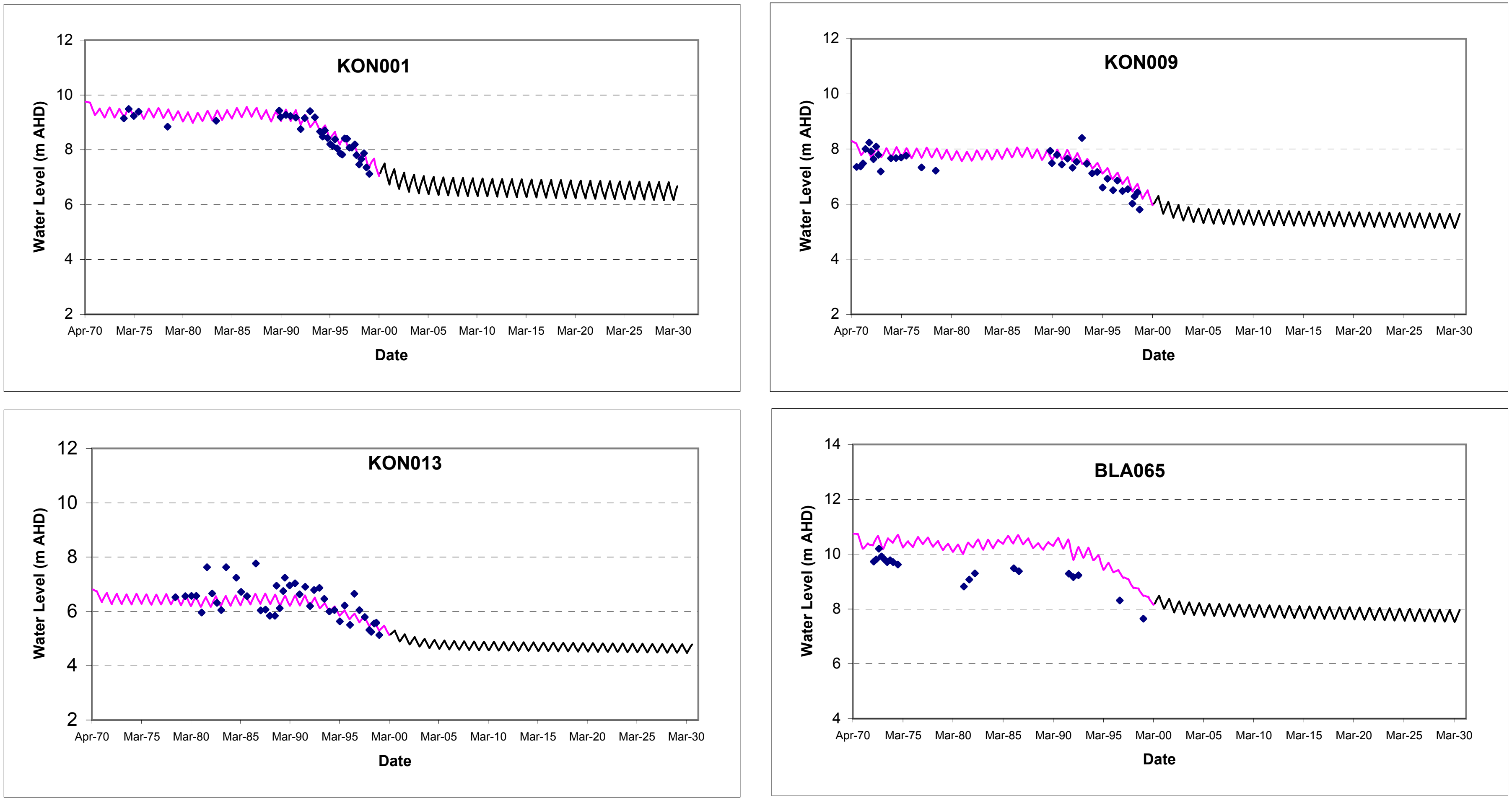
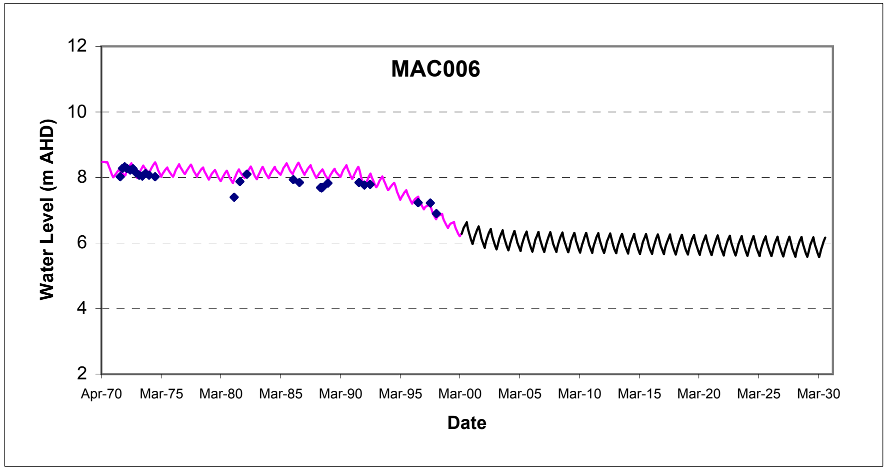
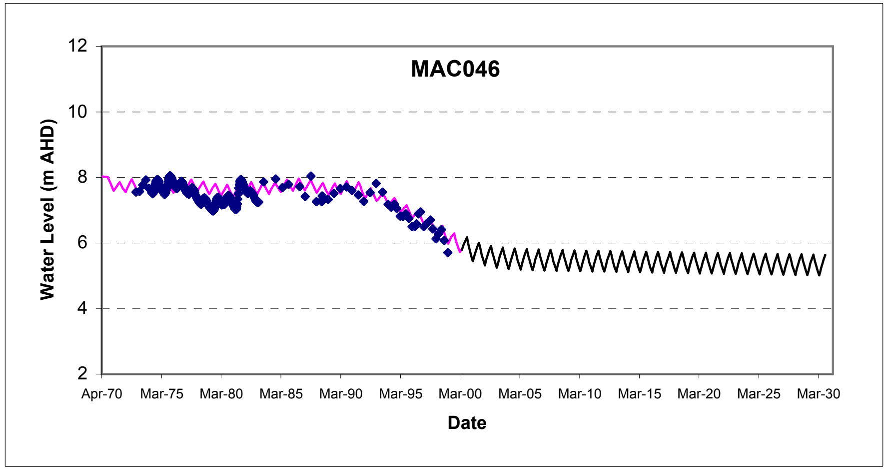


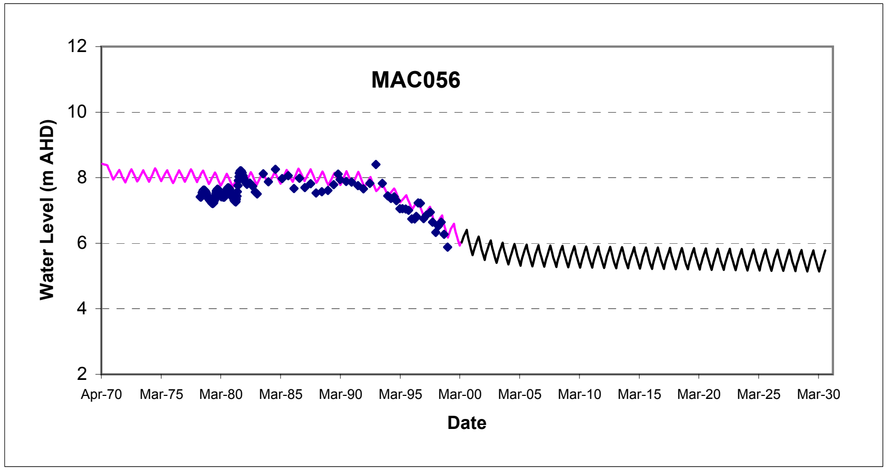
Figure B2-2 *Predicted residual drawdown contours for scenario 2 (2000 to 2030) with small head decline on the northern boundary.*

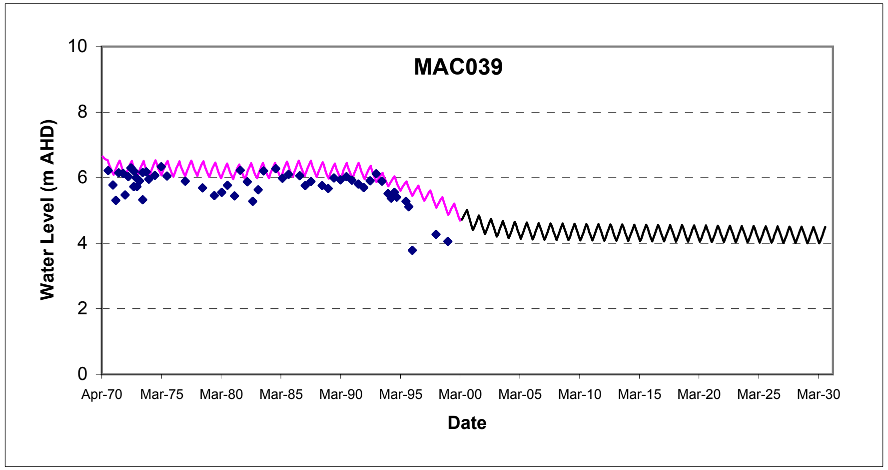


Appendix B2-3 *Hydrographs for Scenario 2 with small head decline on the northern boundary (1970-2030)*

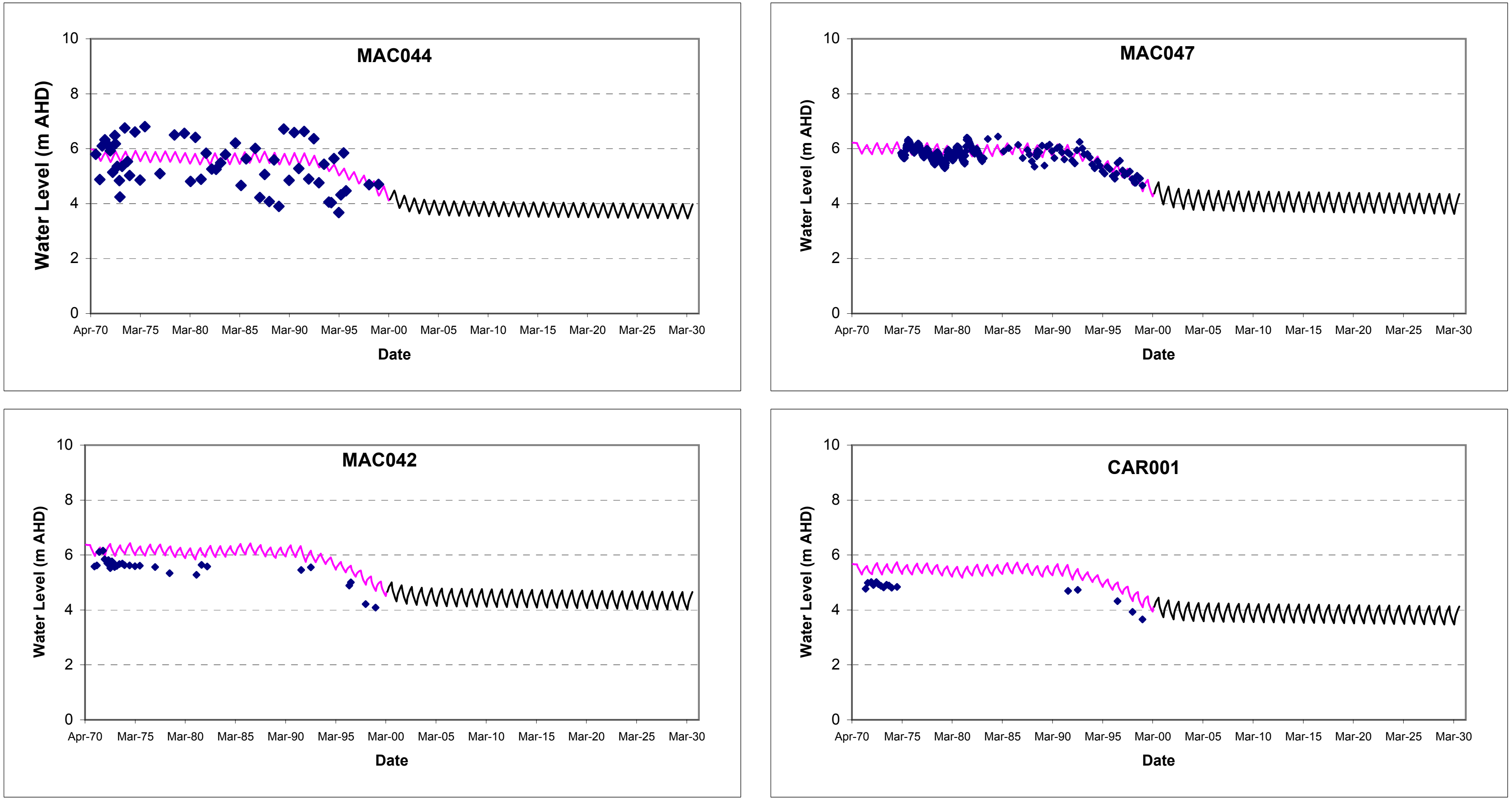




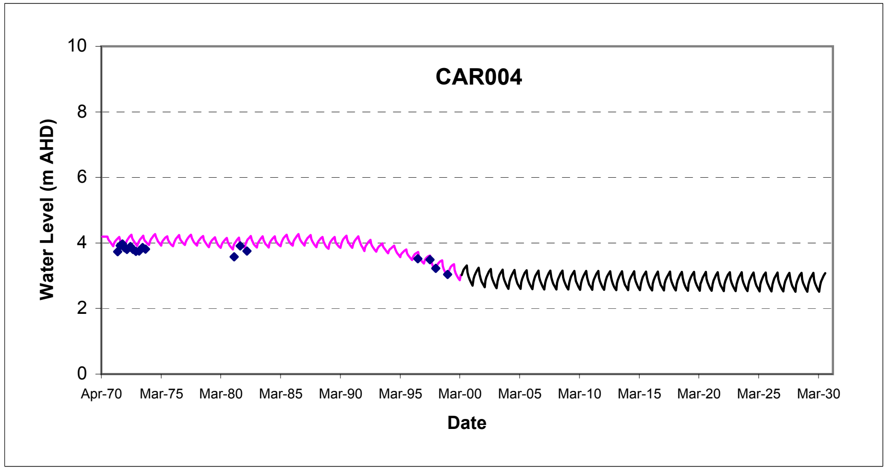


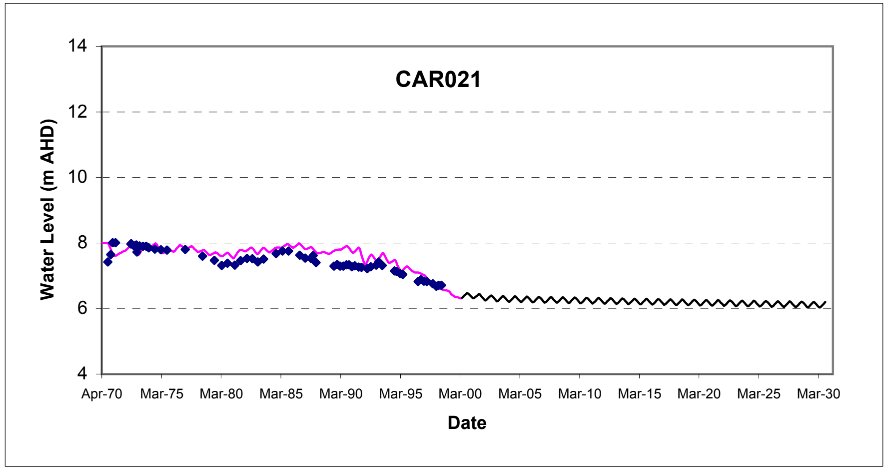


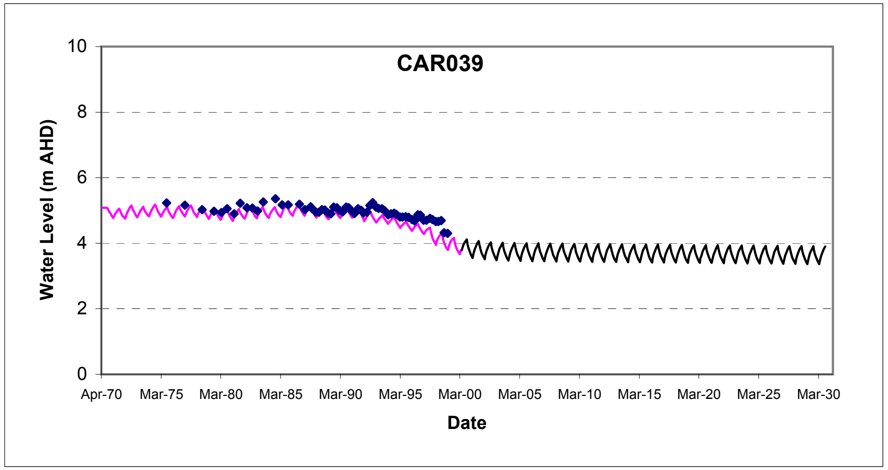
Appendix B2-4 *Hydrographs for Scenario 2 with small head decline on the northern boundary (1970-2030)*

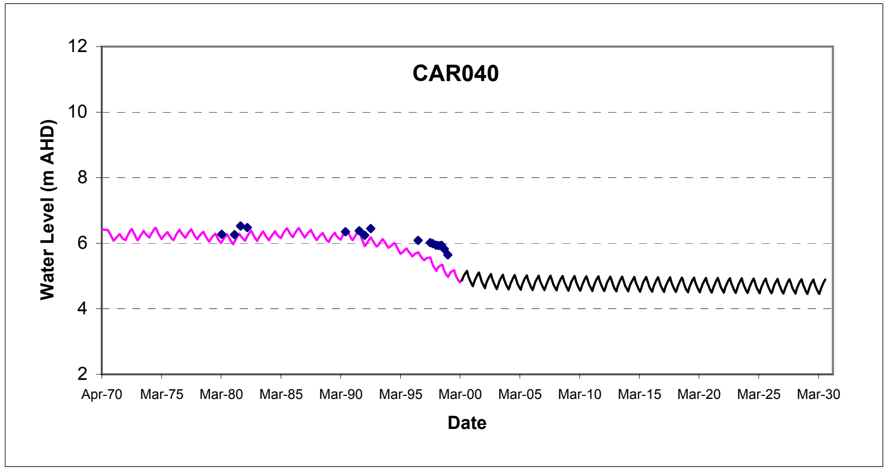


Appendix B2-5 *Hydrographs for Scenario 2 with small head decline on the northern boundary (1970-2030)*









Appendix B2-6 *Hydrographs for Scenario 2 with small head decline on the northern boundary (1970-2030)*

Appendix B3

Scenario 2: Results with a large head decline on the northern boundary

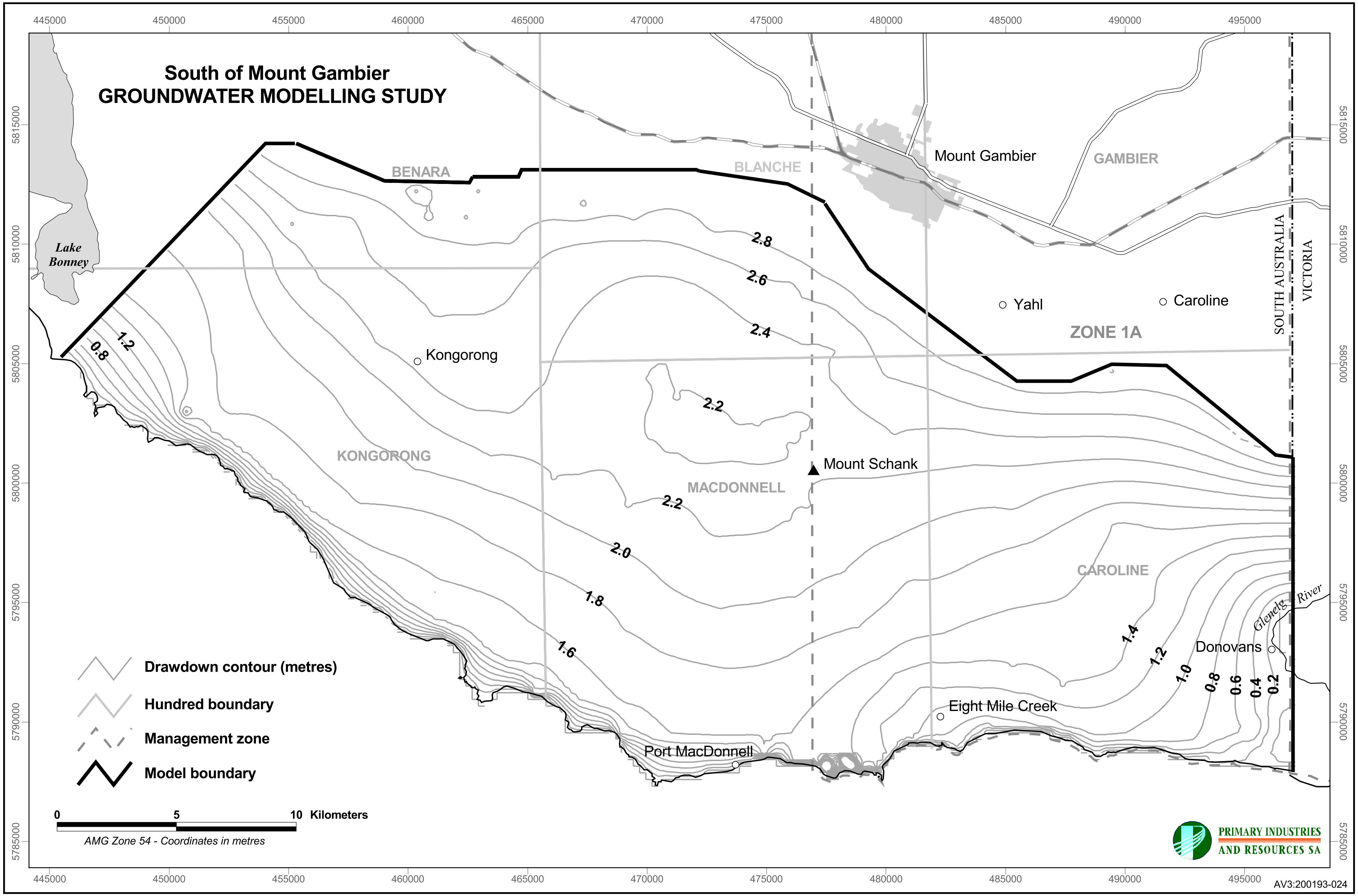


Figure B3-1 *Predicted maximum drawdown contours for scenario 2 (2000 to 2030) with large head decline on the northern boundary.*

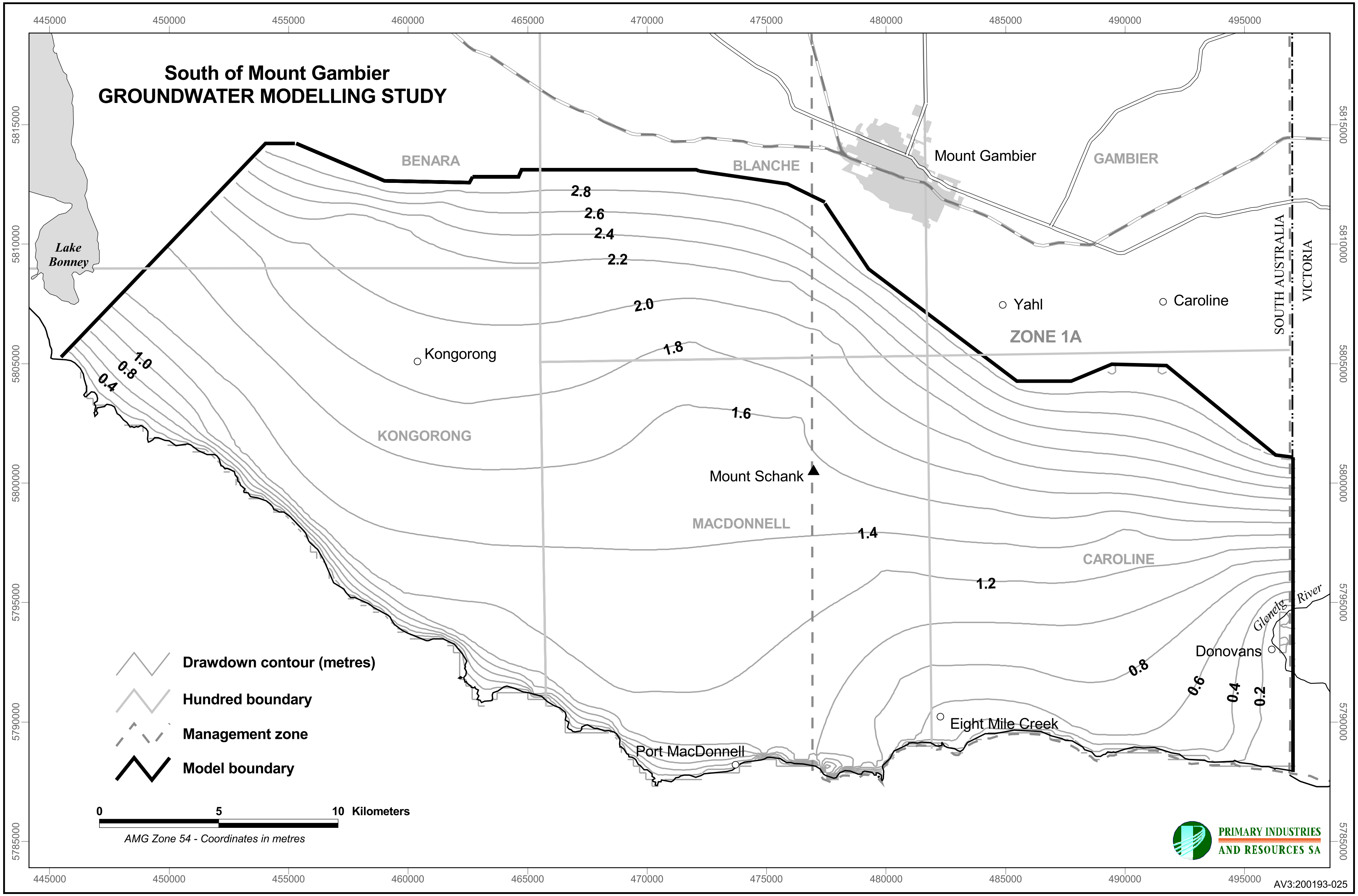
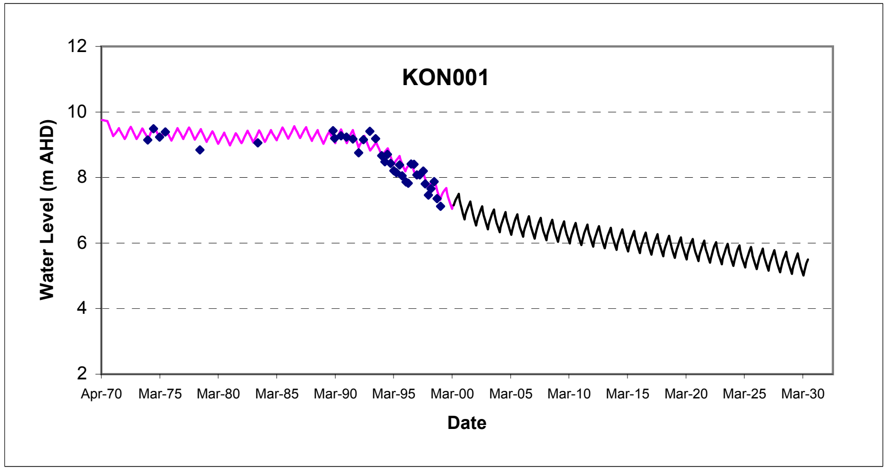
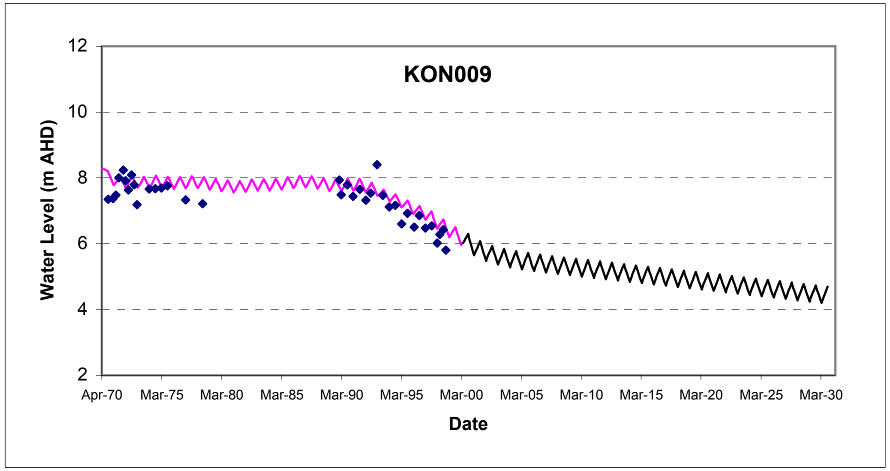
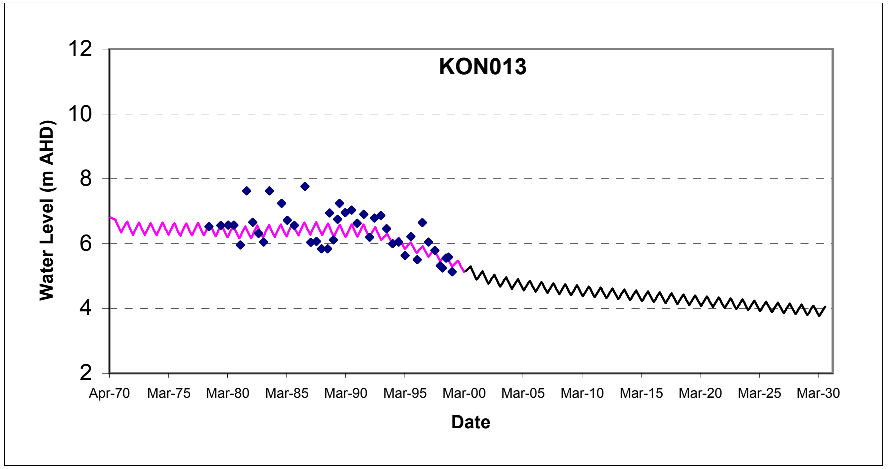
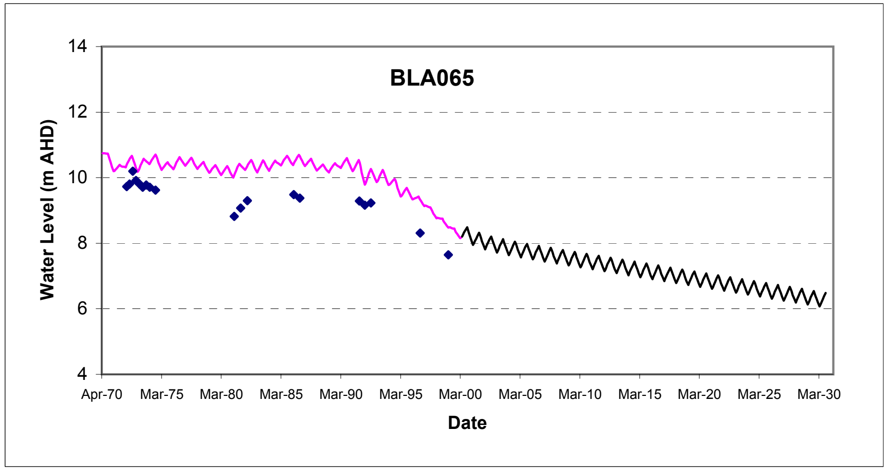


Figure B3-2 *Predicted residual drawdown contours for scenario 2 (2000 to 2030) with large head decline on the northern boundary.*

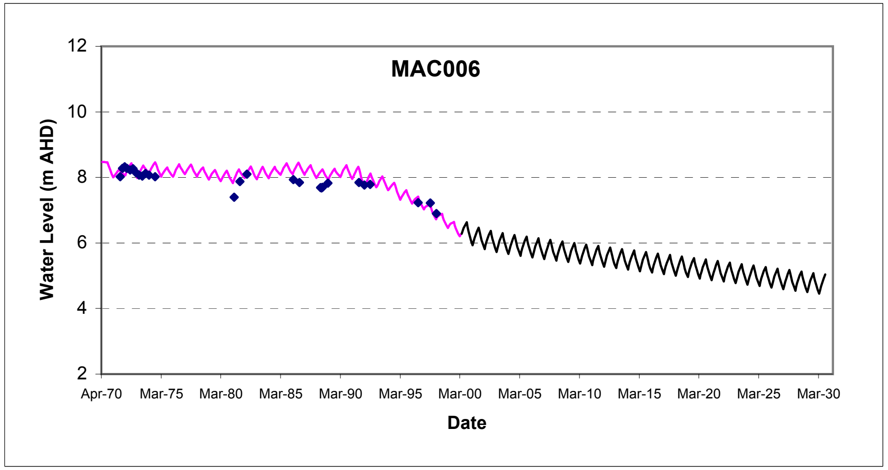


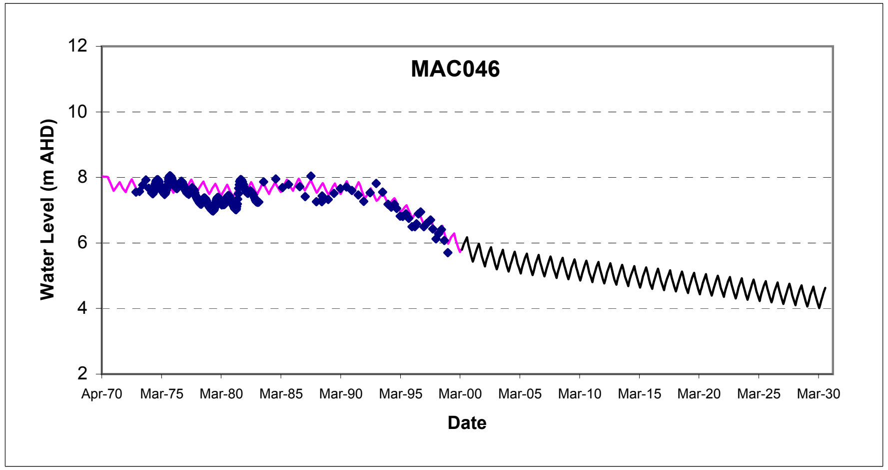


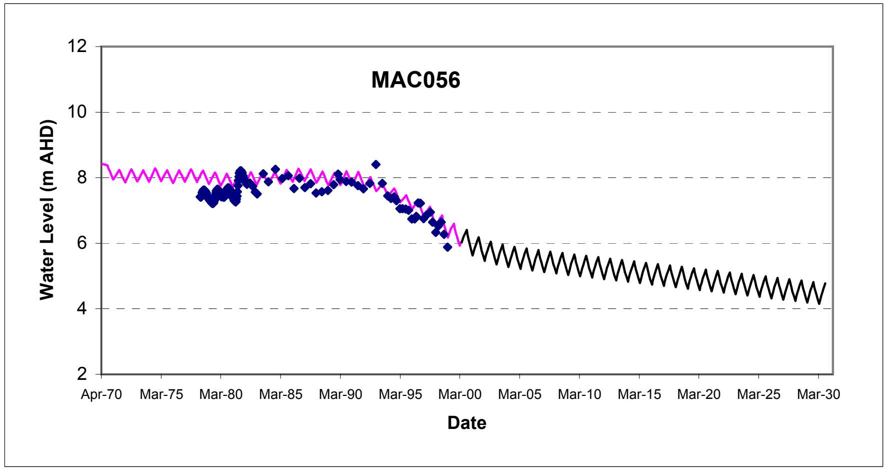


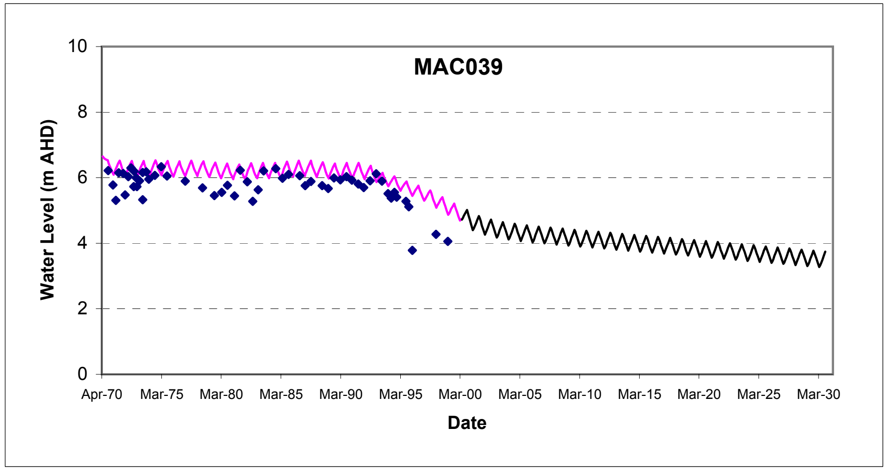


Appendix B3-3 *Hydrographs for Scenario 2 with large head decline on the northern boundary (1970-2030)*

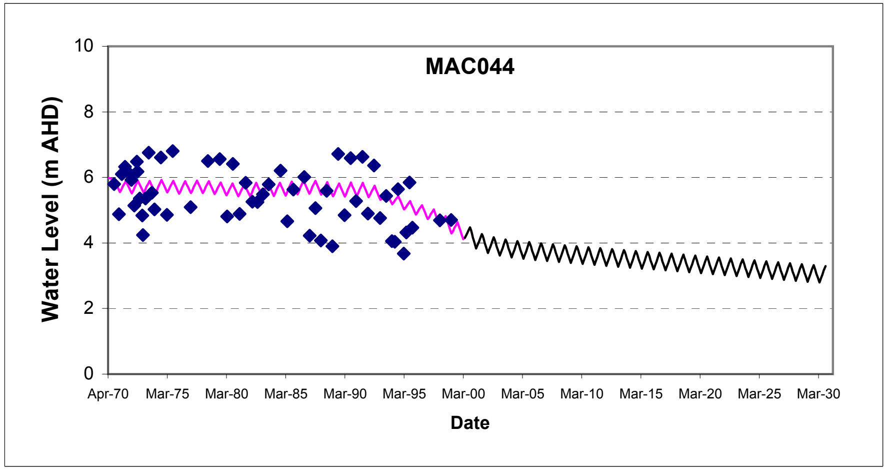


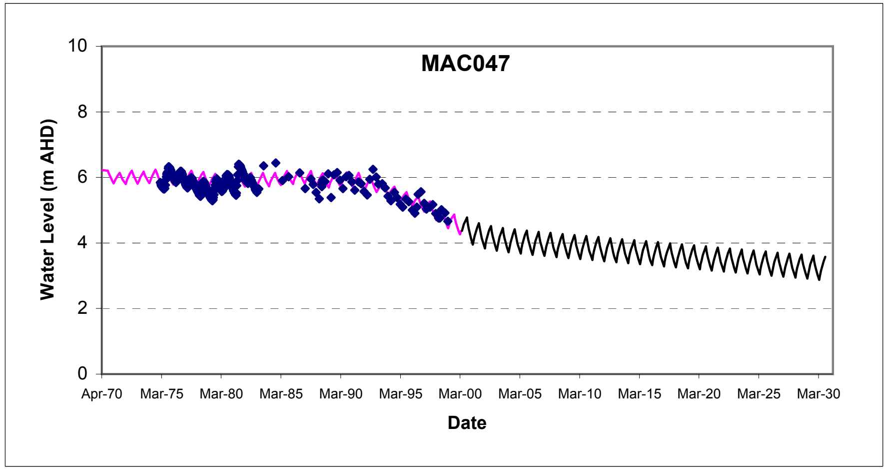


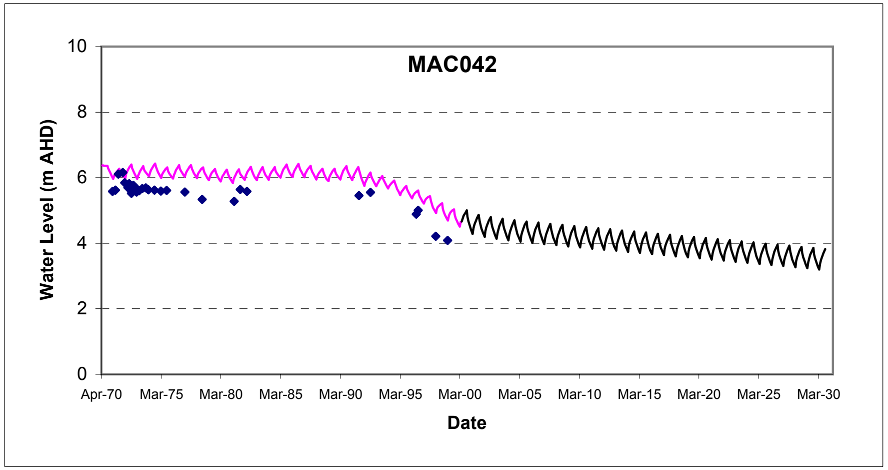


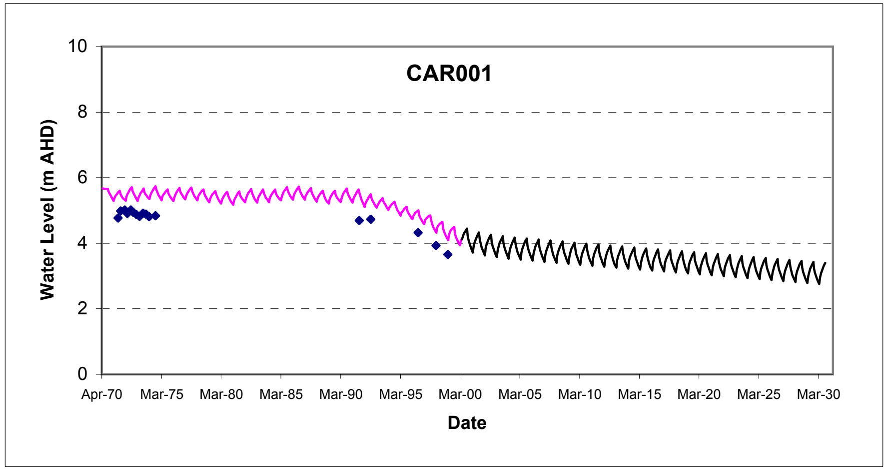


Appendix B3-4 *Hydrographs for Scenario 2 with large head decline on the northern boundary (1970-2030)*

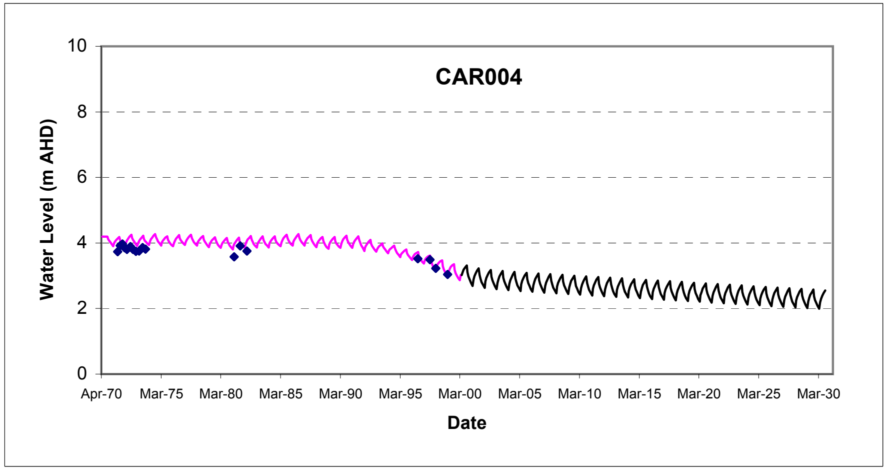


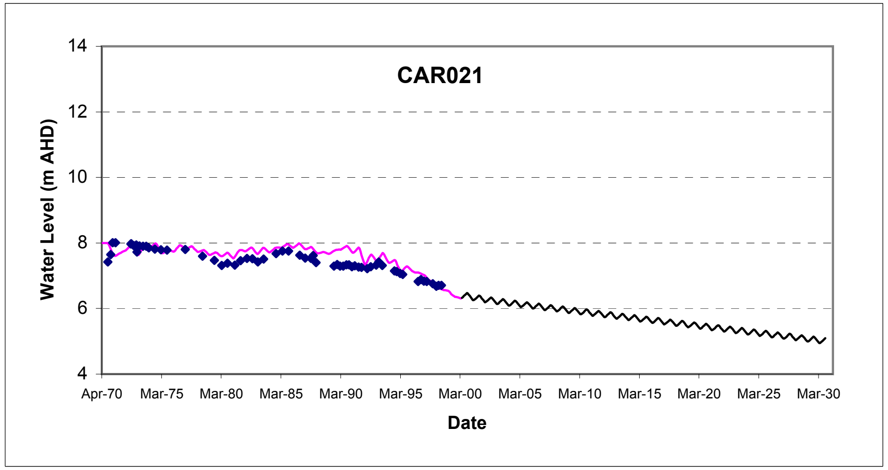


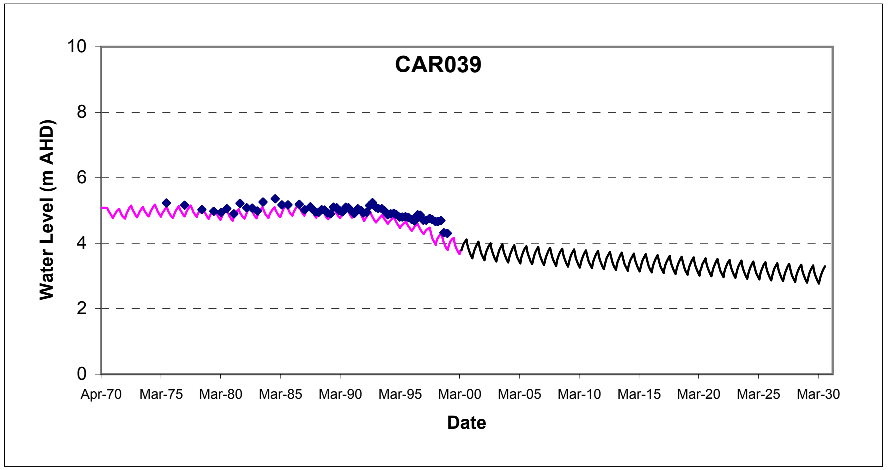


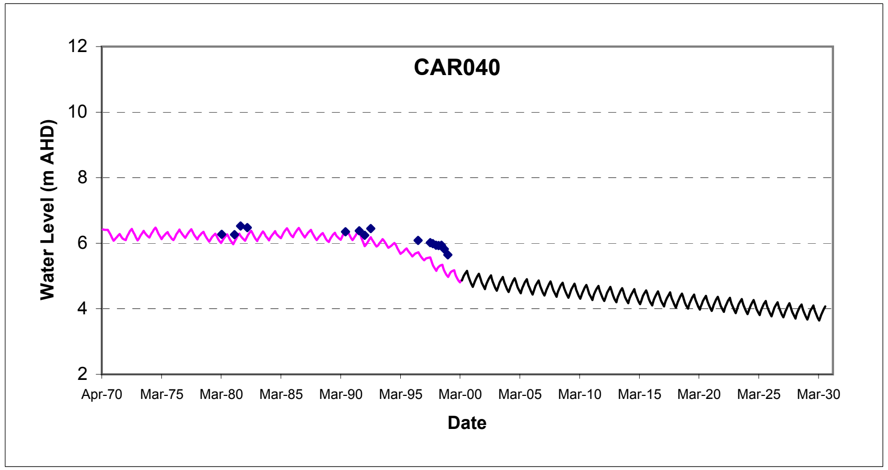


Appendix B3-5 *Hydrographs for Scenario 2 with large head decline on the northern boundary (1970-2030)*









Appendix B3-6 *Hydrographs for Scenario 2 with large head decline on the northern boundary (1970-2030)*

Appendix C1

Scenario 3: Results with no head decline

on the northern boundary

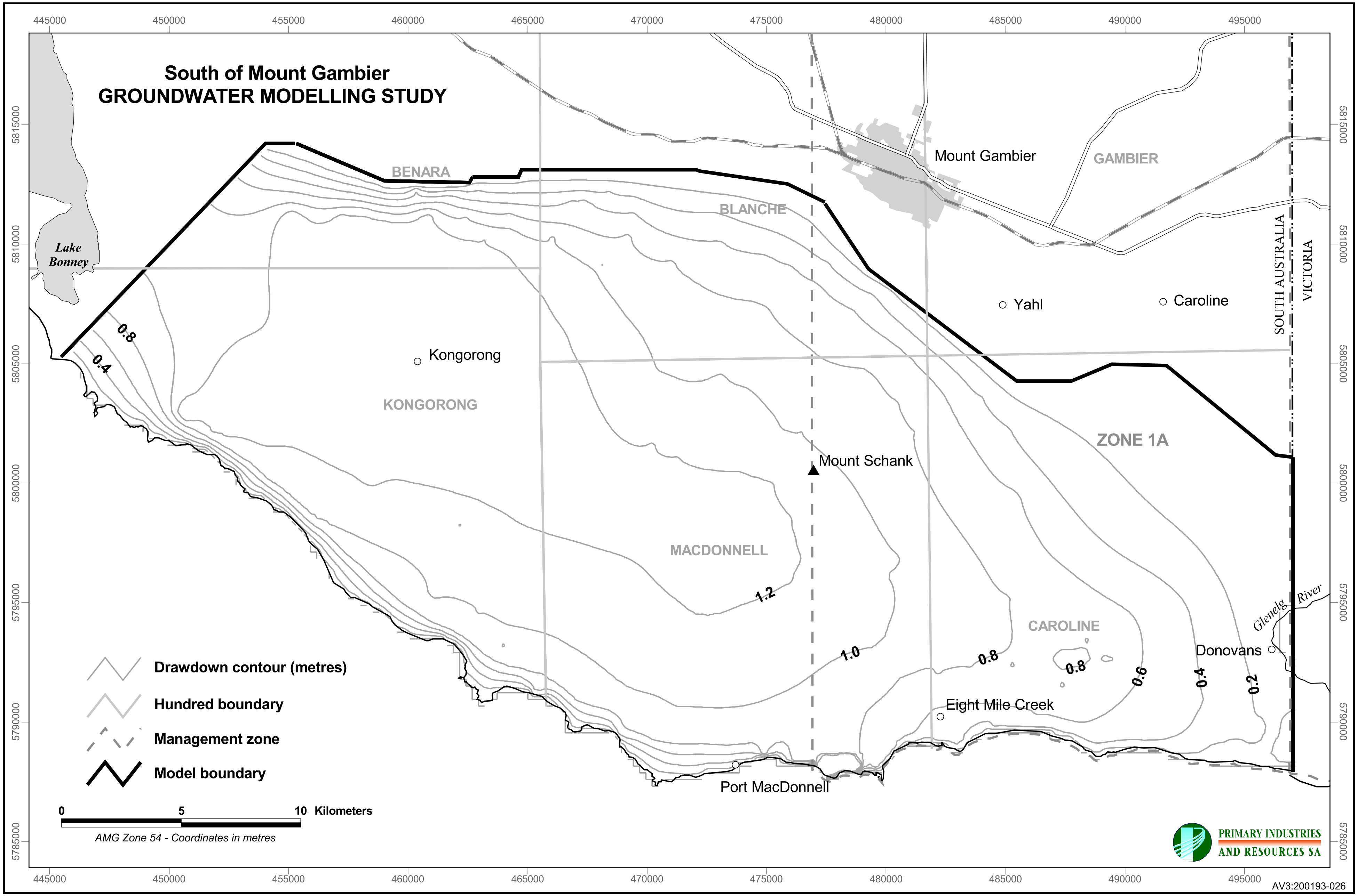


Figure C1-1 *Predicted maximum drawdown contours for scenario 3 (2000 to 2030) with no head decline on the northern boundary.*

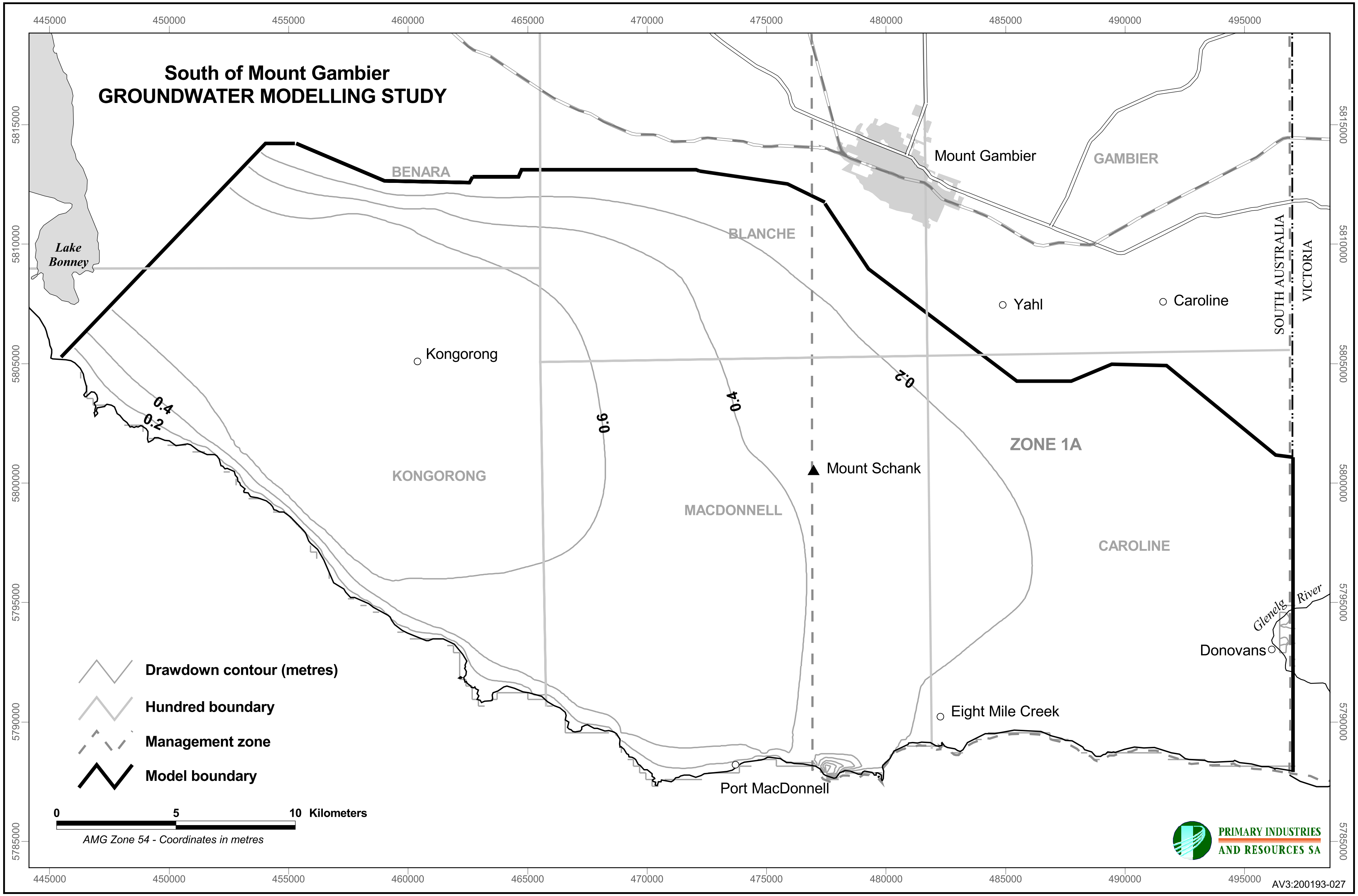
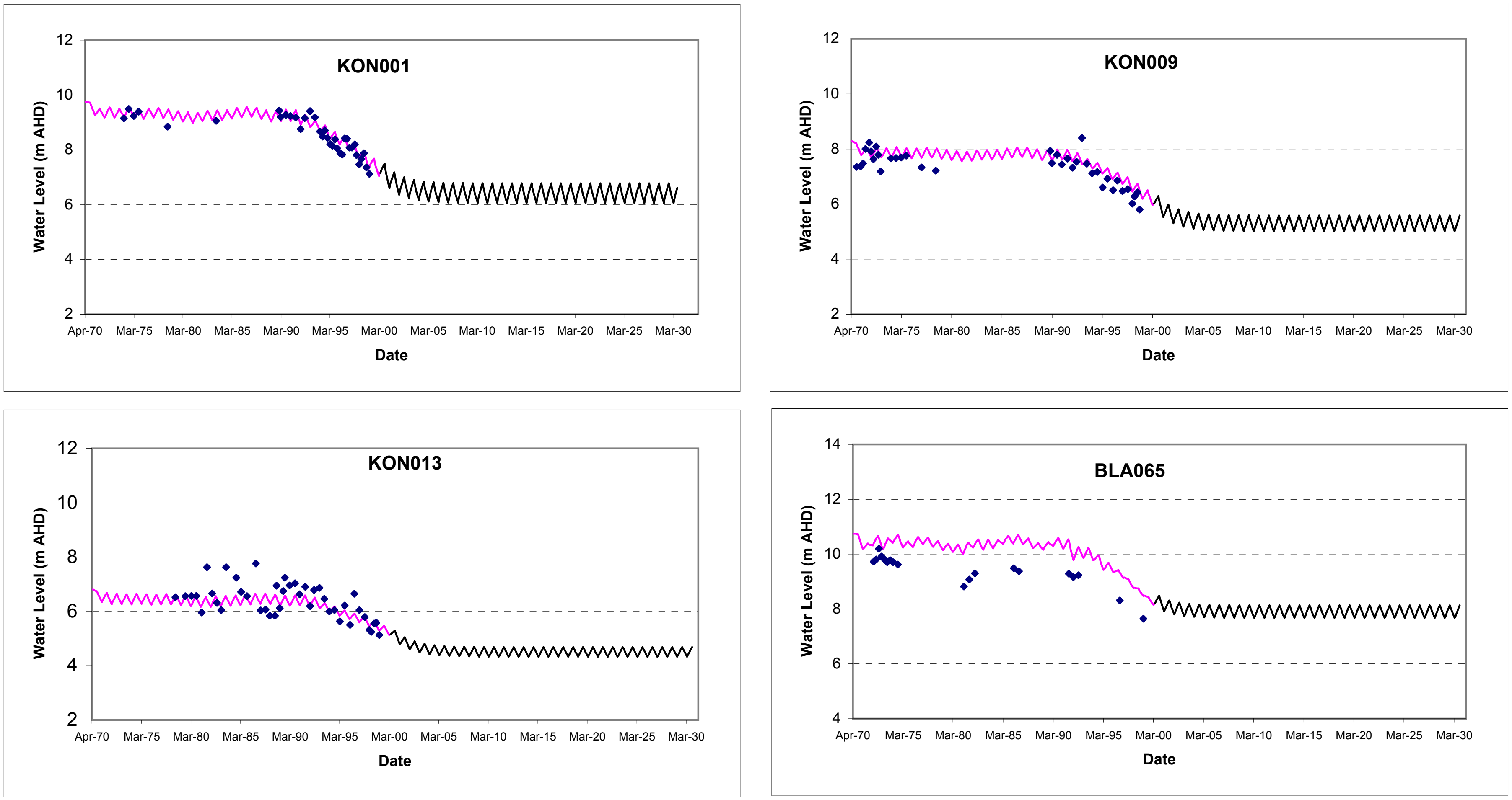
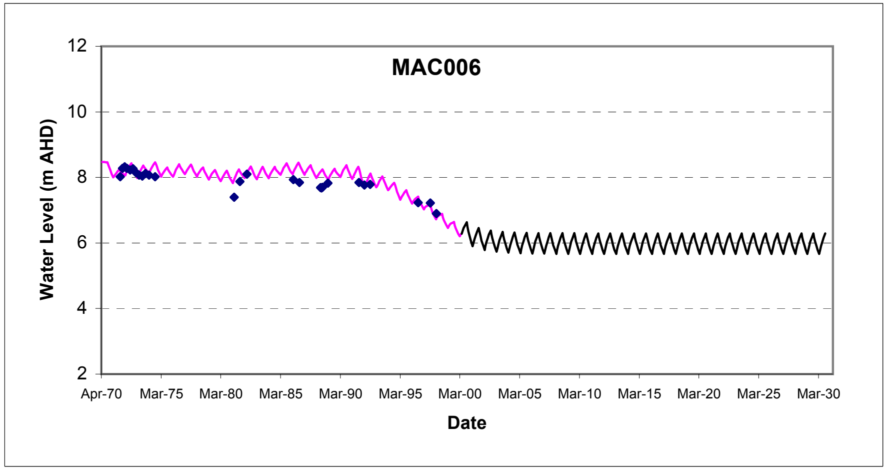
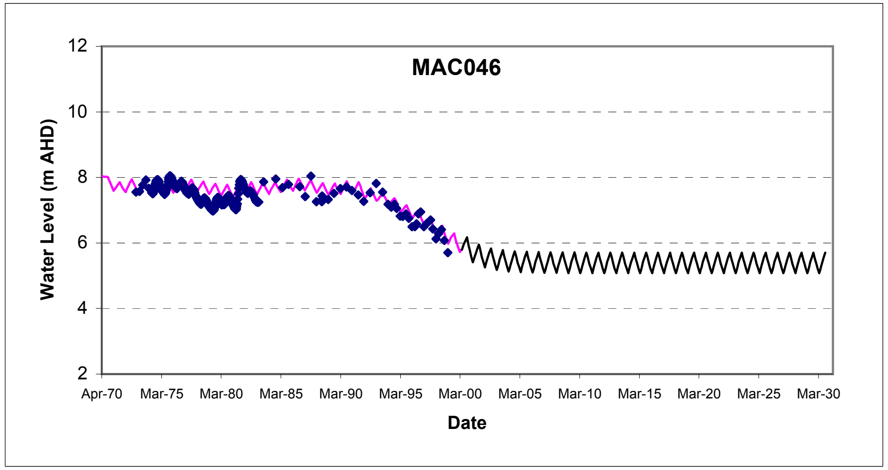


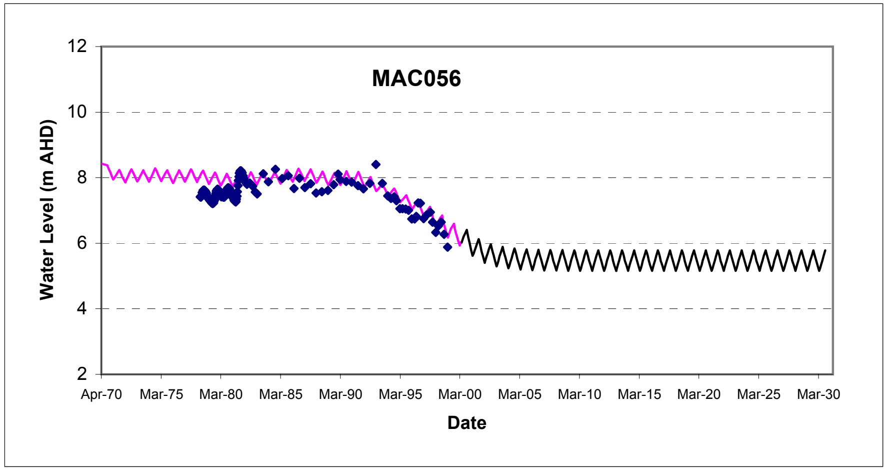
Figure C1-2 *Predicted residual drawdown contours for scenario 3 (2000 to 2030) with no head decline on the northern boundary.*

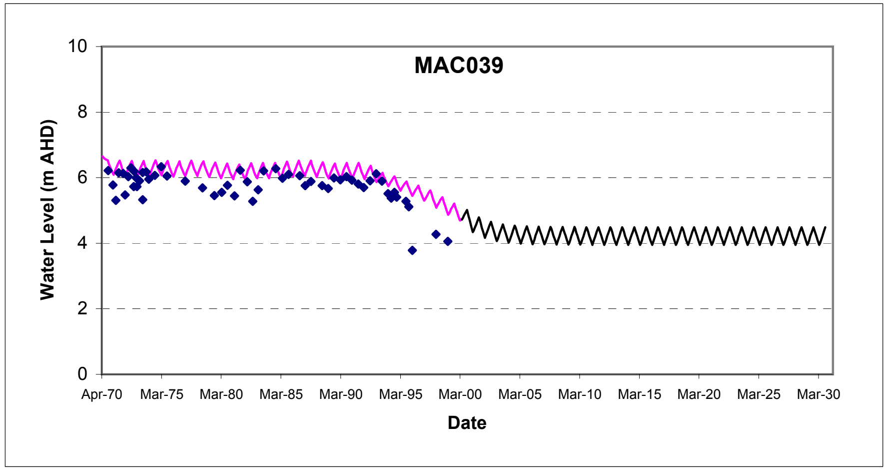


Appendix C1-3 *Hydrographs for Scenario 3 with no head decline on the northern boundary (1970-2030)*

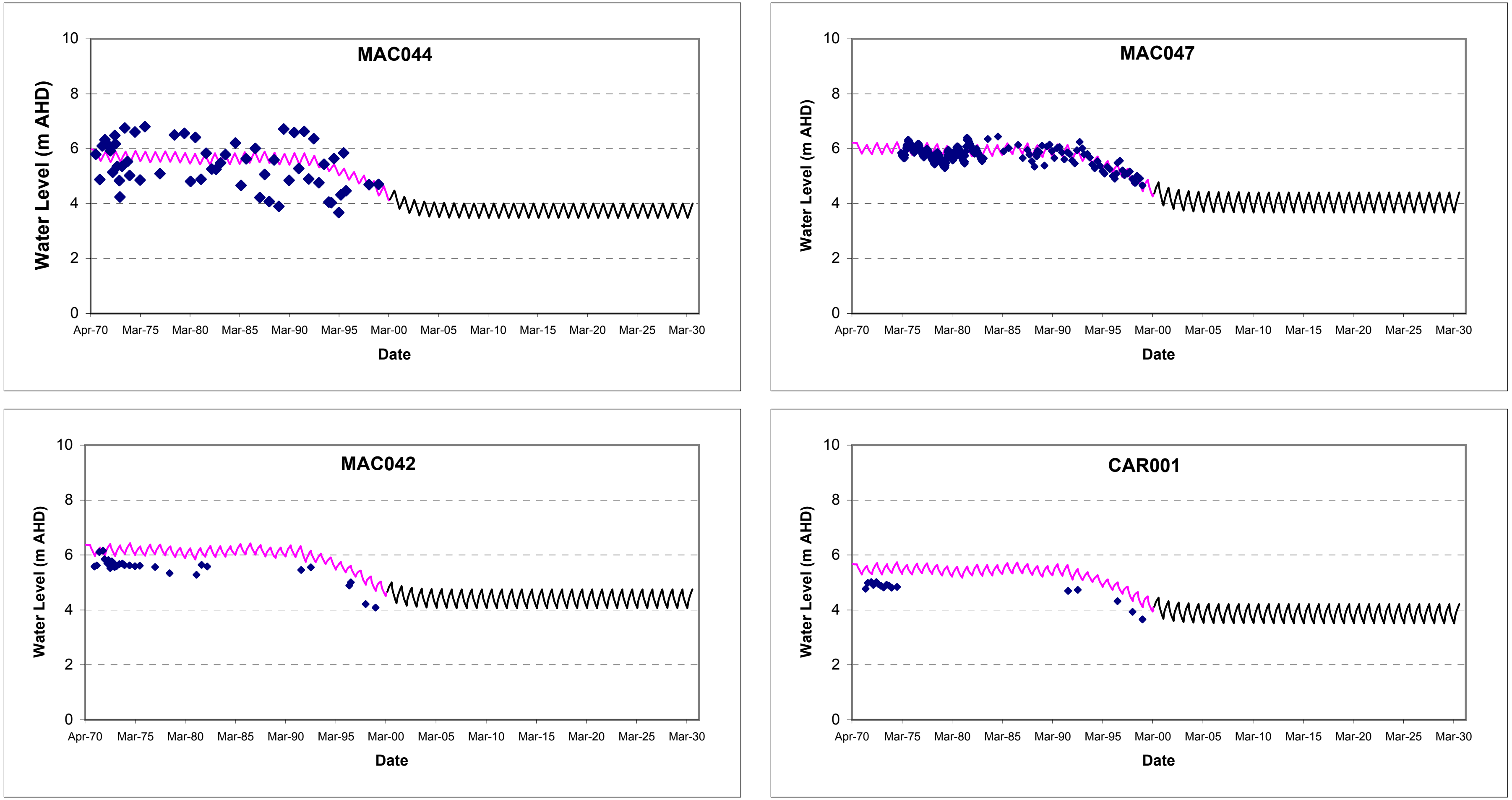




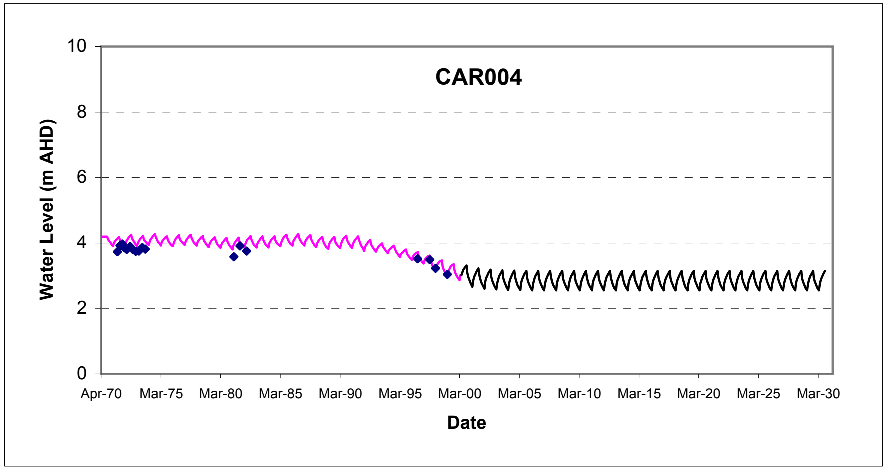


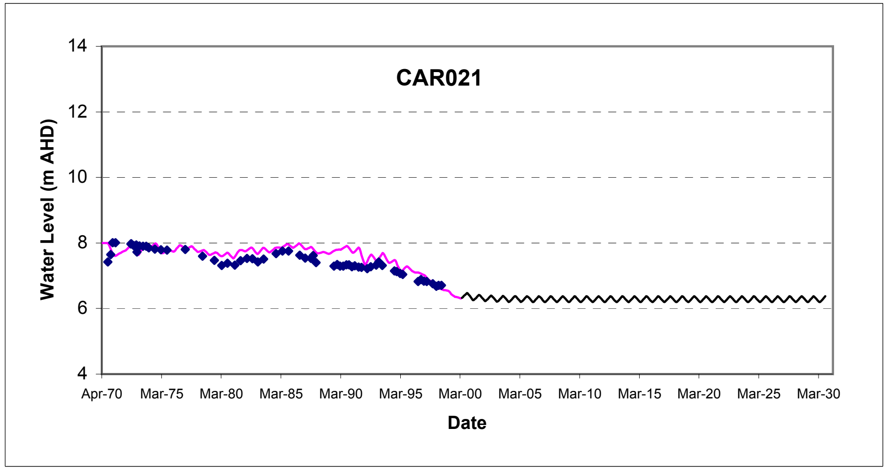


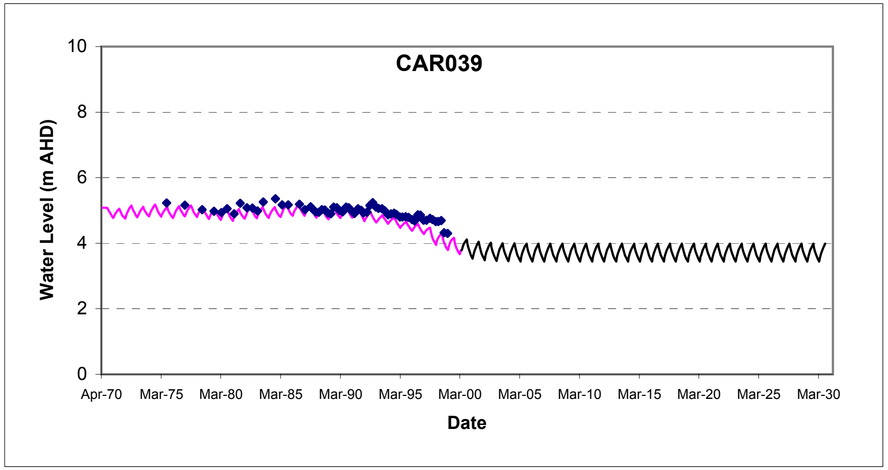
Appendix C1-4 *Hydrographs for Scenario 3 with no head decline on the northern boundary (1970-2030)*

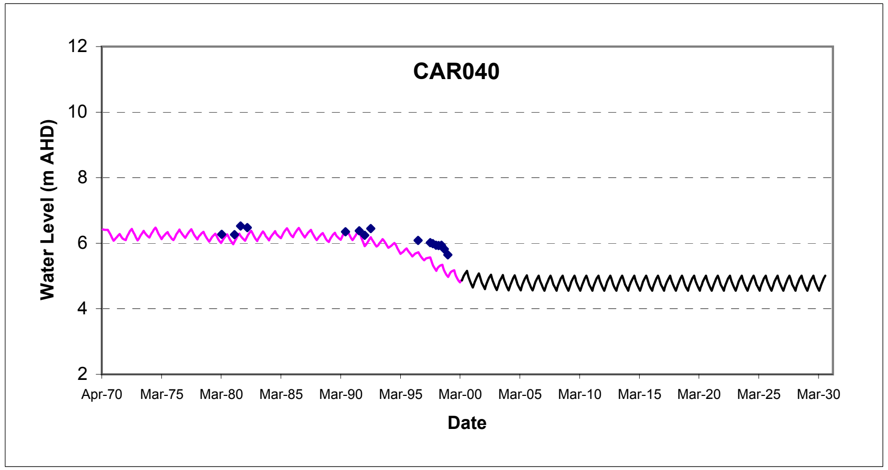


Appendix C1-5 *Hydrographs for Scenario 3 with no head decline on the northern boundary (1970-2030)*









Appendix C1-6 *Hydrographs for Scenario 3 with no head decline on the northern boundary (1970-2030)*

Appendix C2

Scenario 3: Results with a small head decline

on the northern boundary

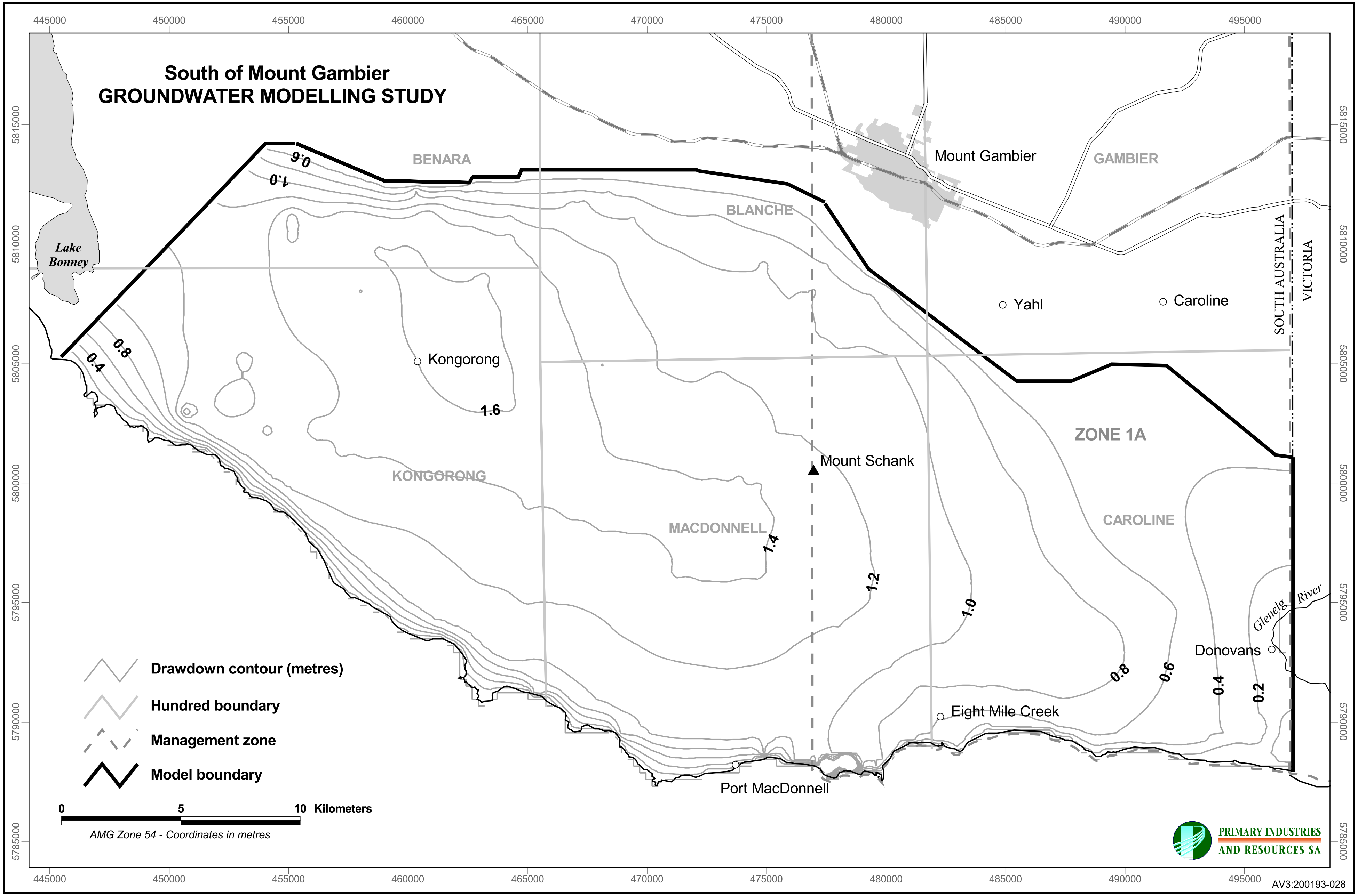


Figure C2-1 *Predicted maximum drawdown contours for scenario 3 (2000 to 2030) with small head decline on the northern boundary.*

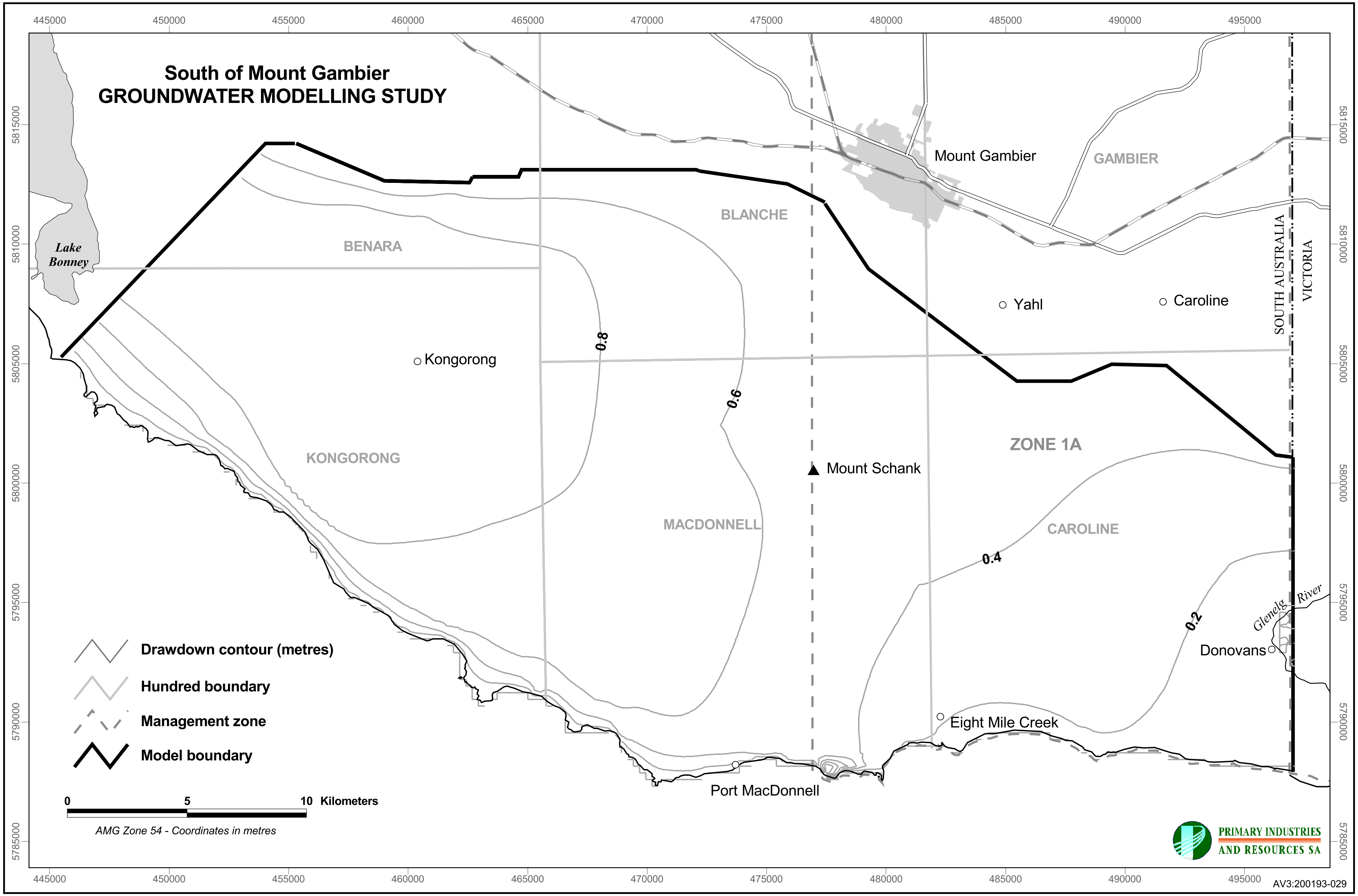
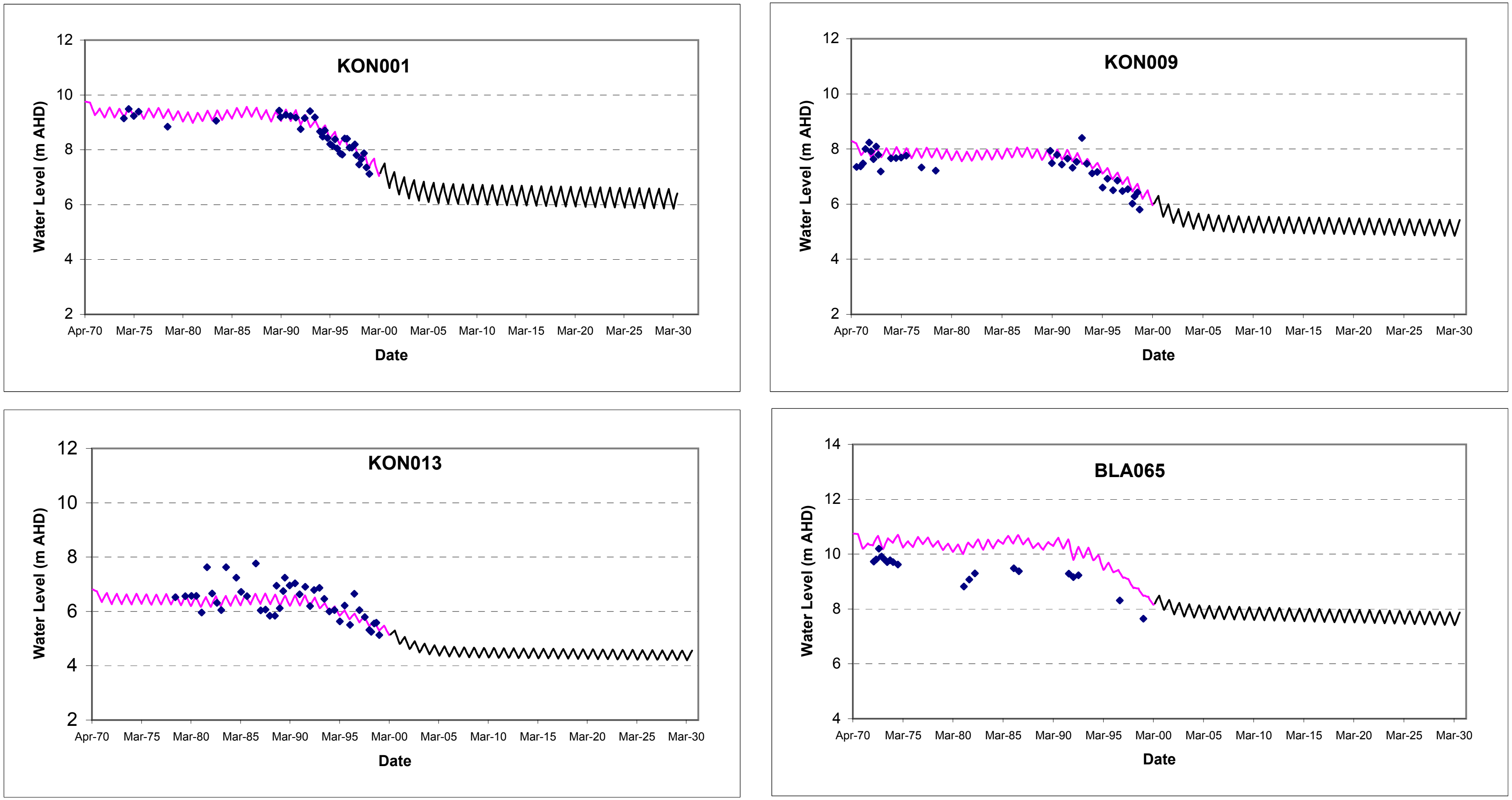
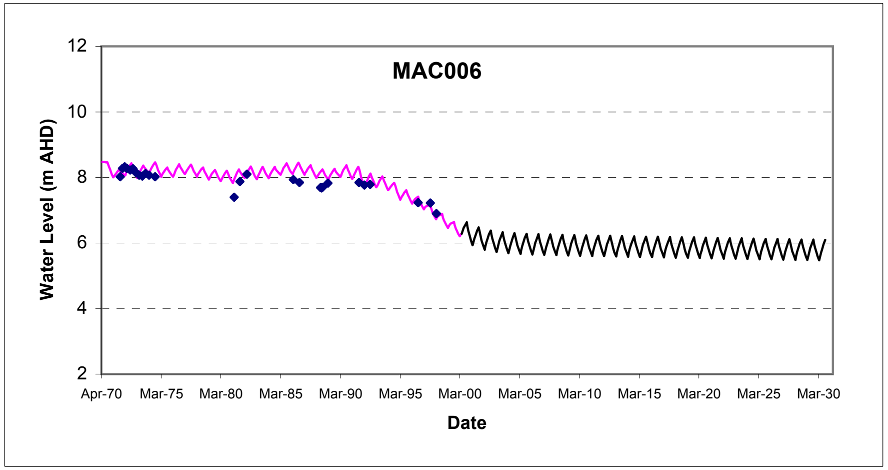
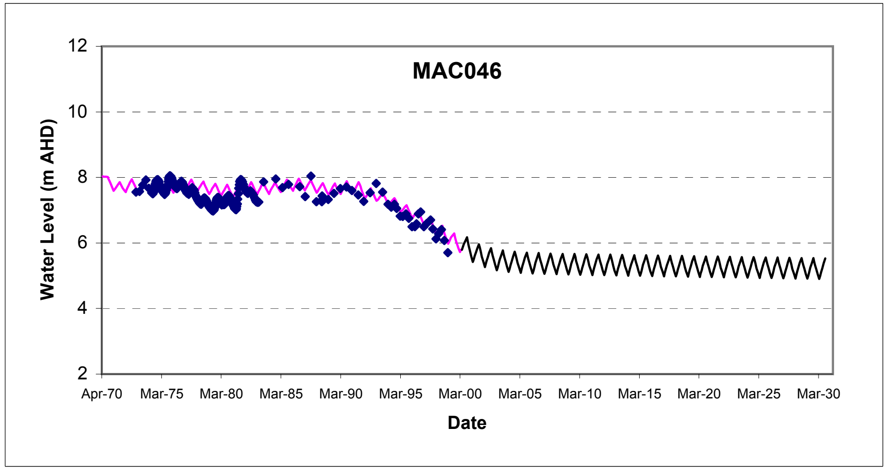


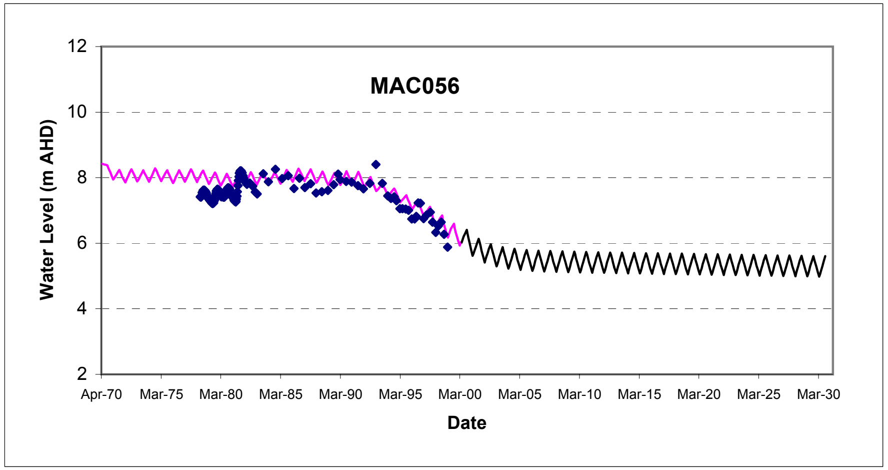
Figure C2-2 *Predicted residual drawdown contours for scenario 3 (2000 to 2030) with small head decline on the northern boundary.*

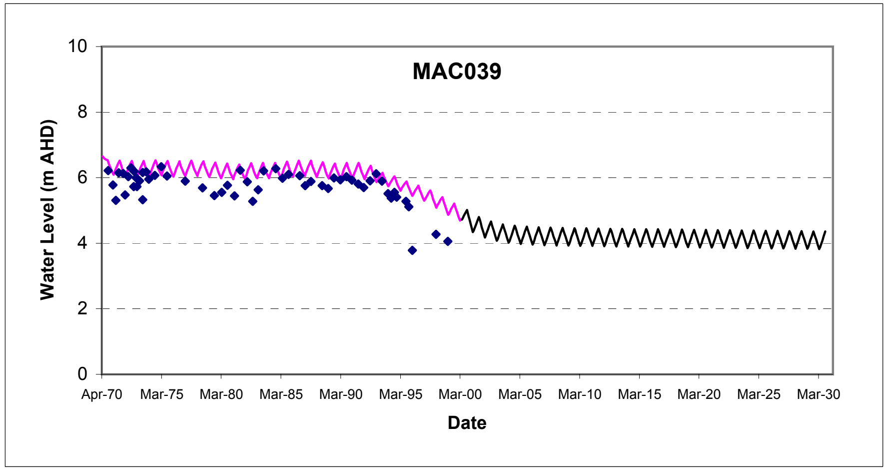


Appendix C2-3 *Hydrographs for Scenario 3 with small head decline on the northern boundary (1970-2030)*

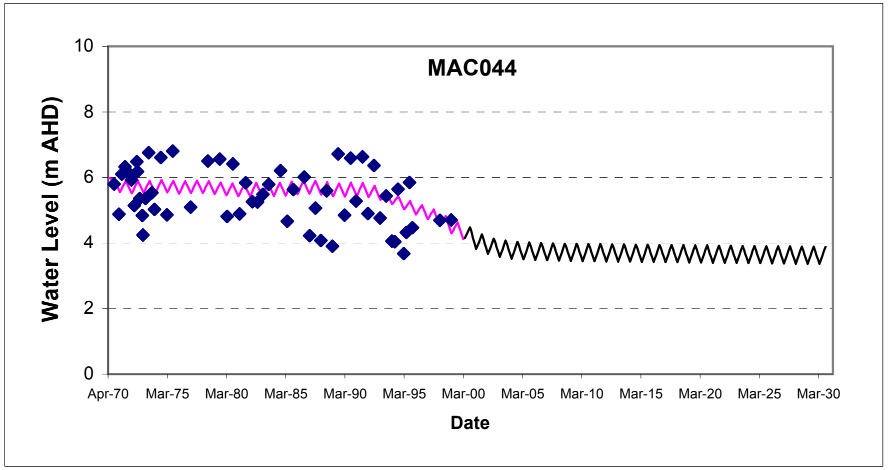


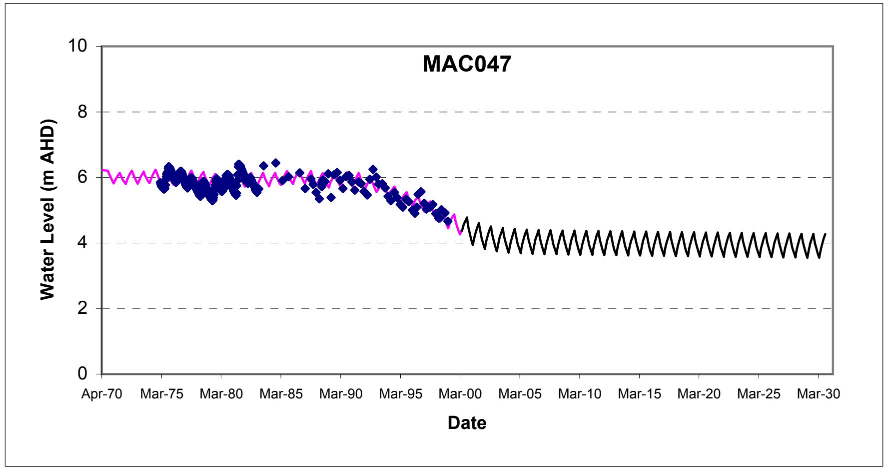


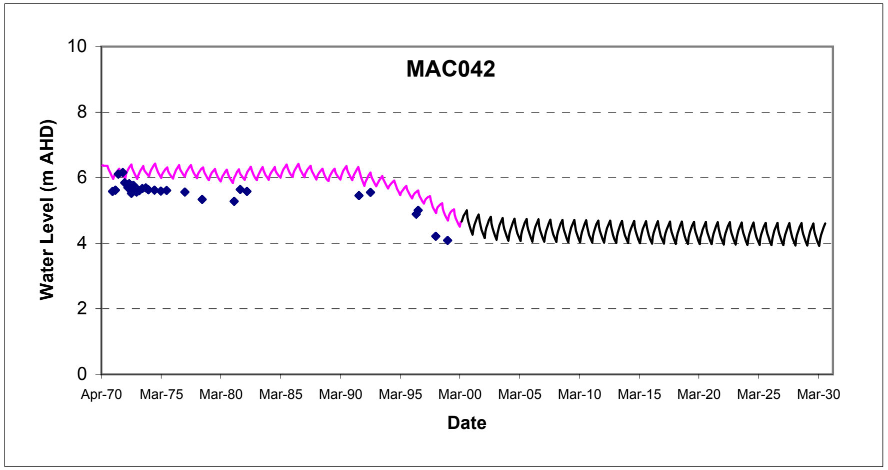


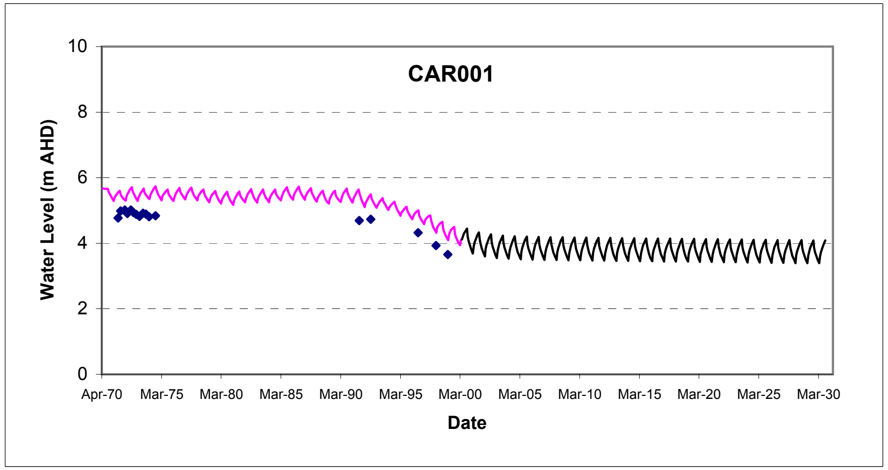


Appendix C2-4 *Hydrographs for Scenario 3 with small head decline on the northern boundary (1970-2030)*

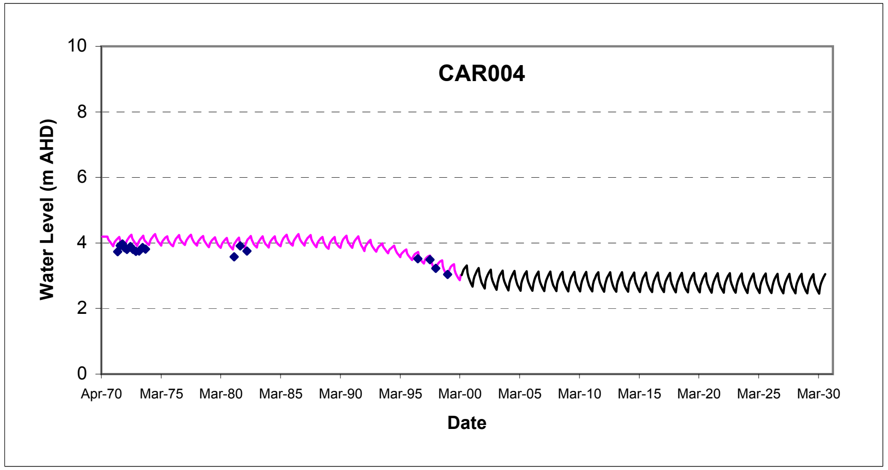


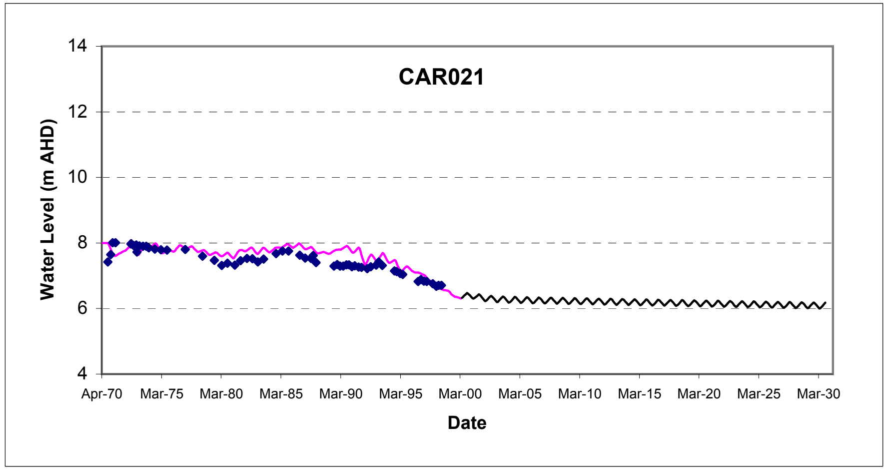


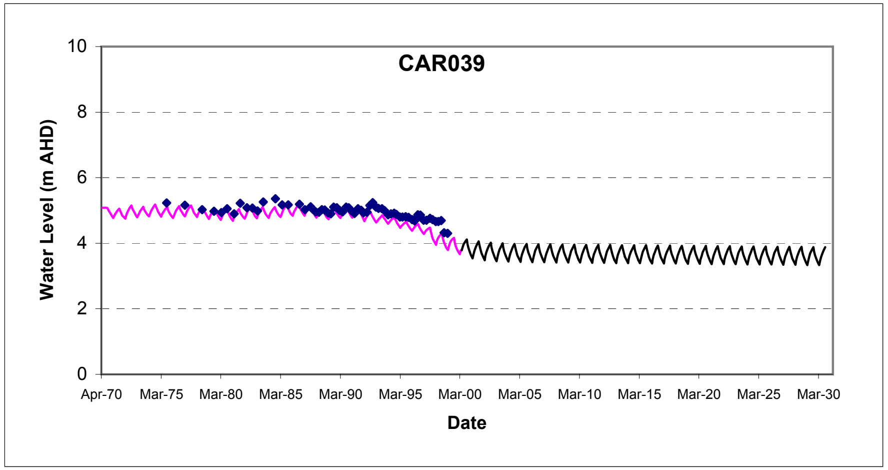


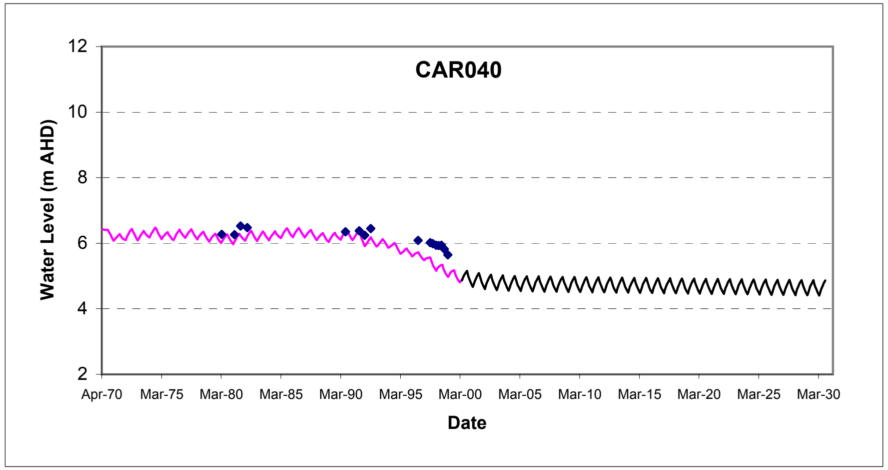


Appendix C2-5 *Hydrographs for Scenario 3 with small head decline on the northern boundary (1970-2030)*









Appendix C2-6 *Hydrographs for Scenario 3 with small head decline on the northern boundary (1970-2030)*

Appendix C3

Scenario 3: Results with a large head decline

on the northern boundary

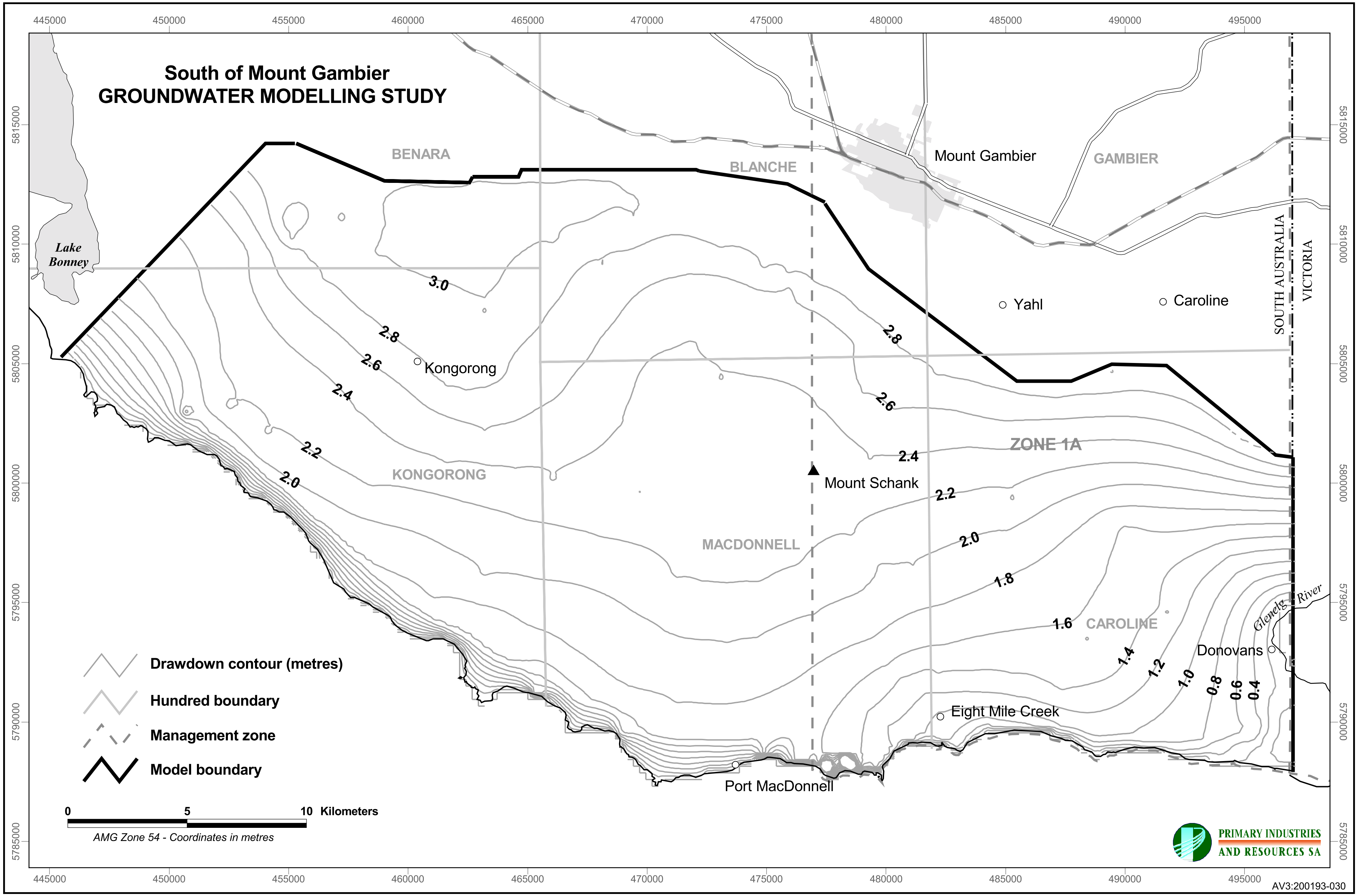


Figure C3-1 Predicted maximum drawdown contours for scenario 3 (2000 to 2030) with large head decline on the northern boundary.

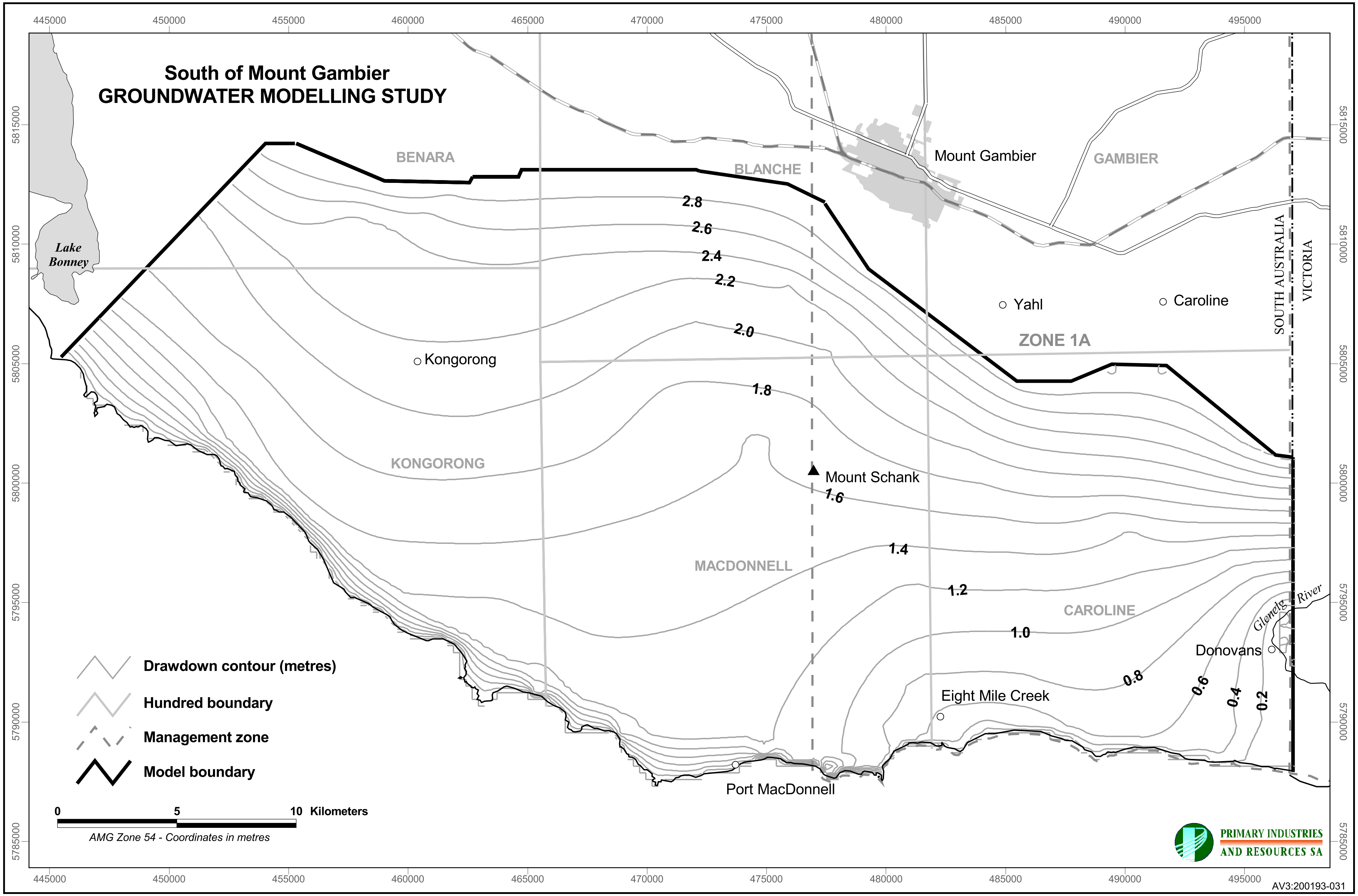
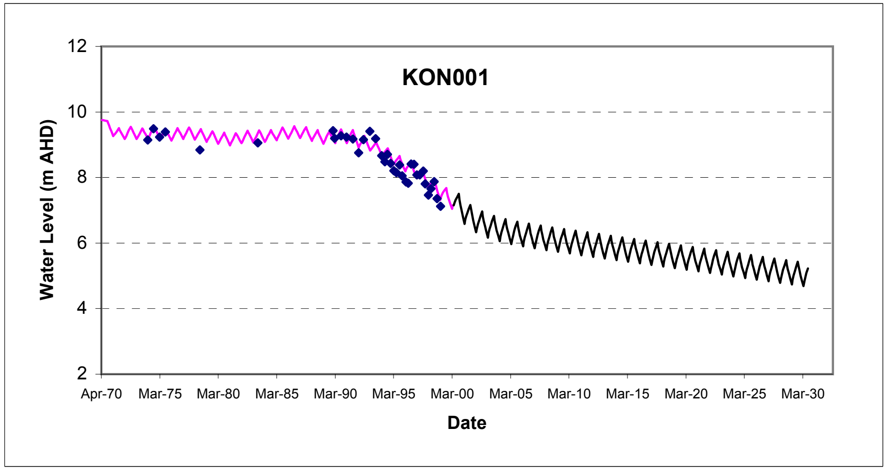
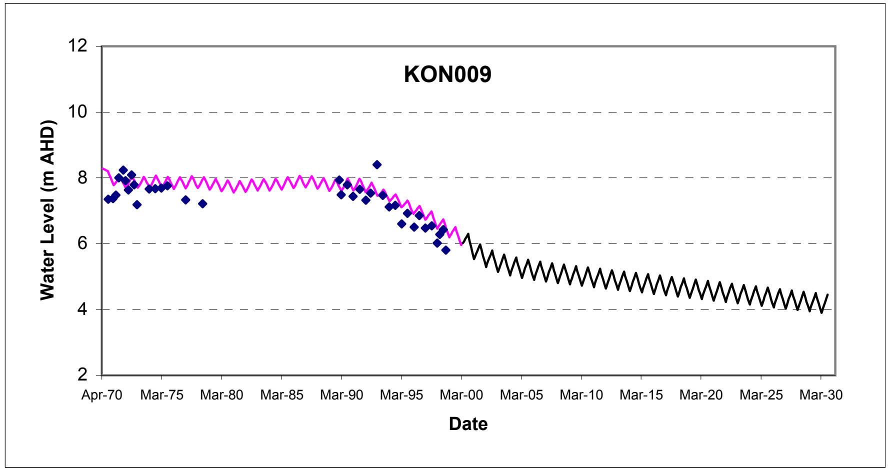
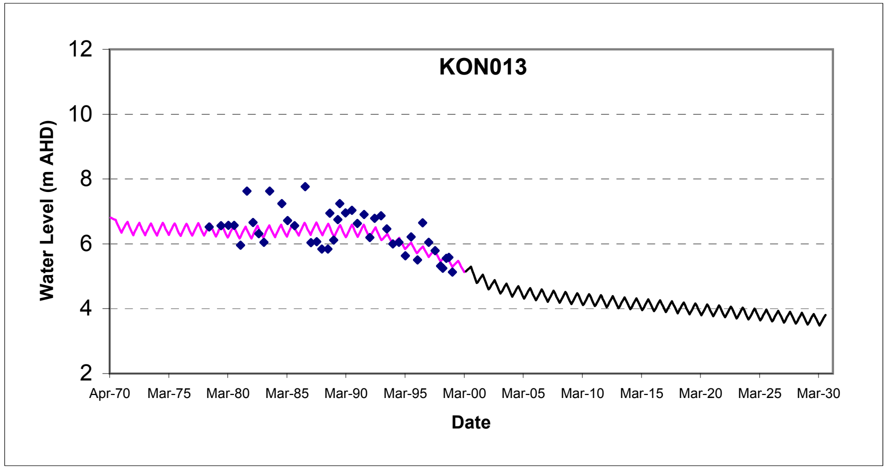
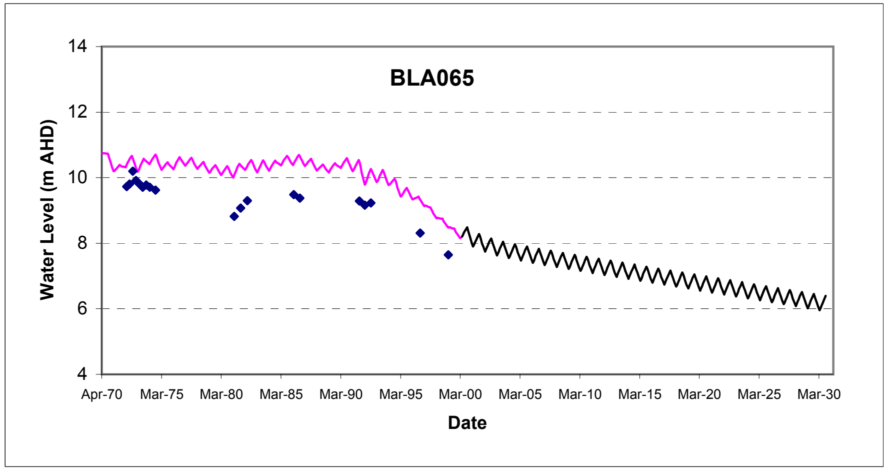


Figure C3-2 *Predicted residual drawdown contours for scenario 3 (2000 to 2030) with large head decline on the northern boundary.*

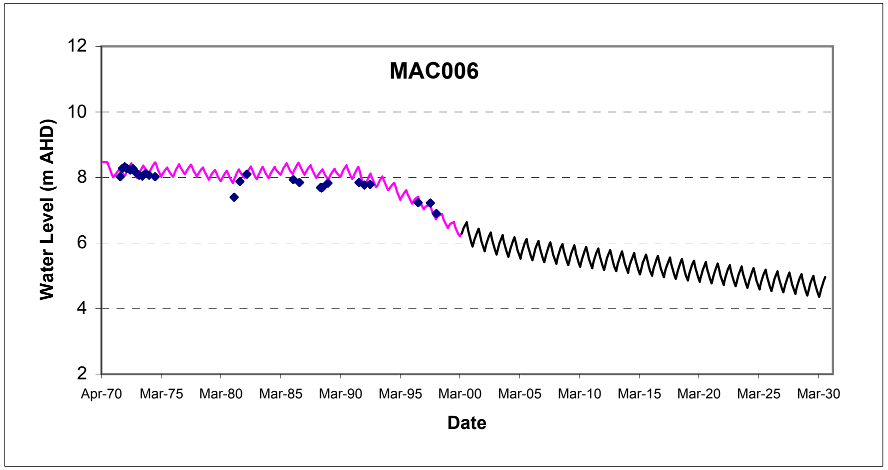


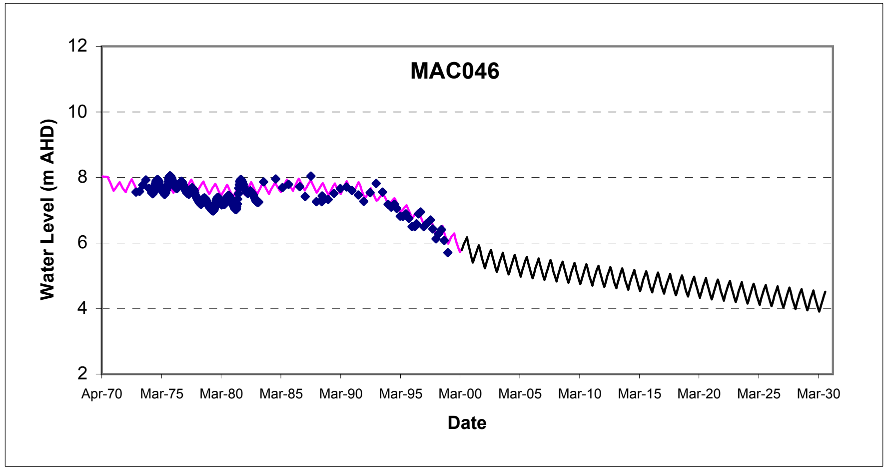


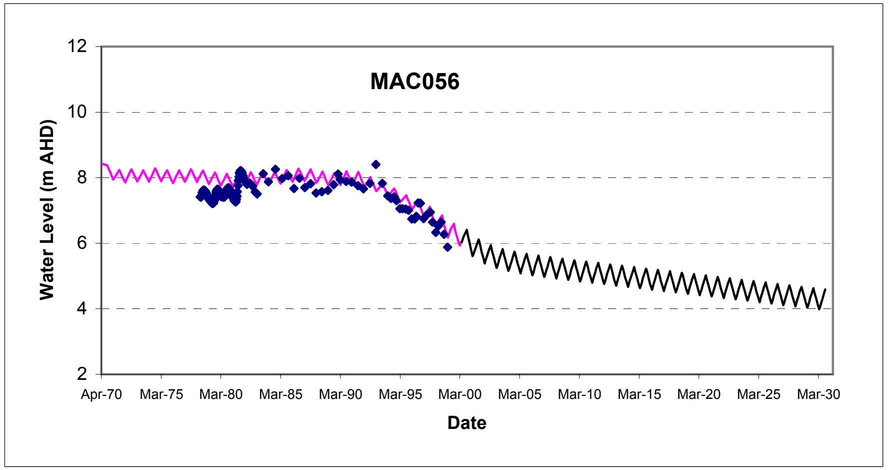


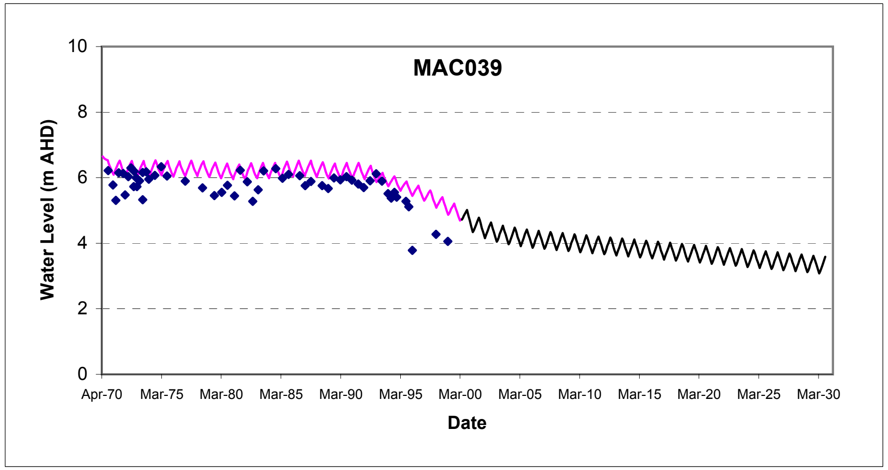


Appendix C3-3 *Hydrographs for Scenario 3 with large head decline on the northern boundary (1970-2030)*

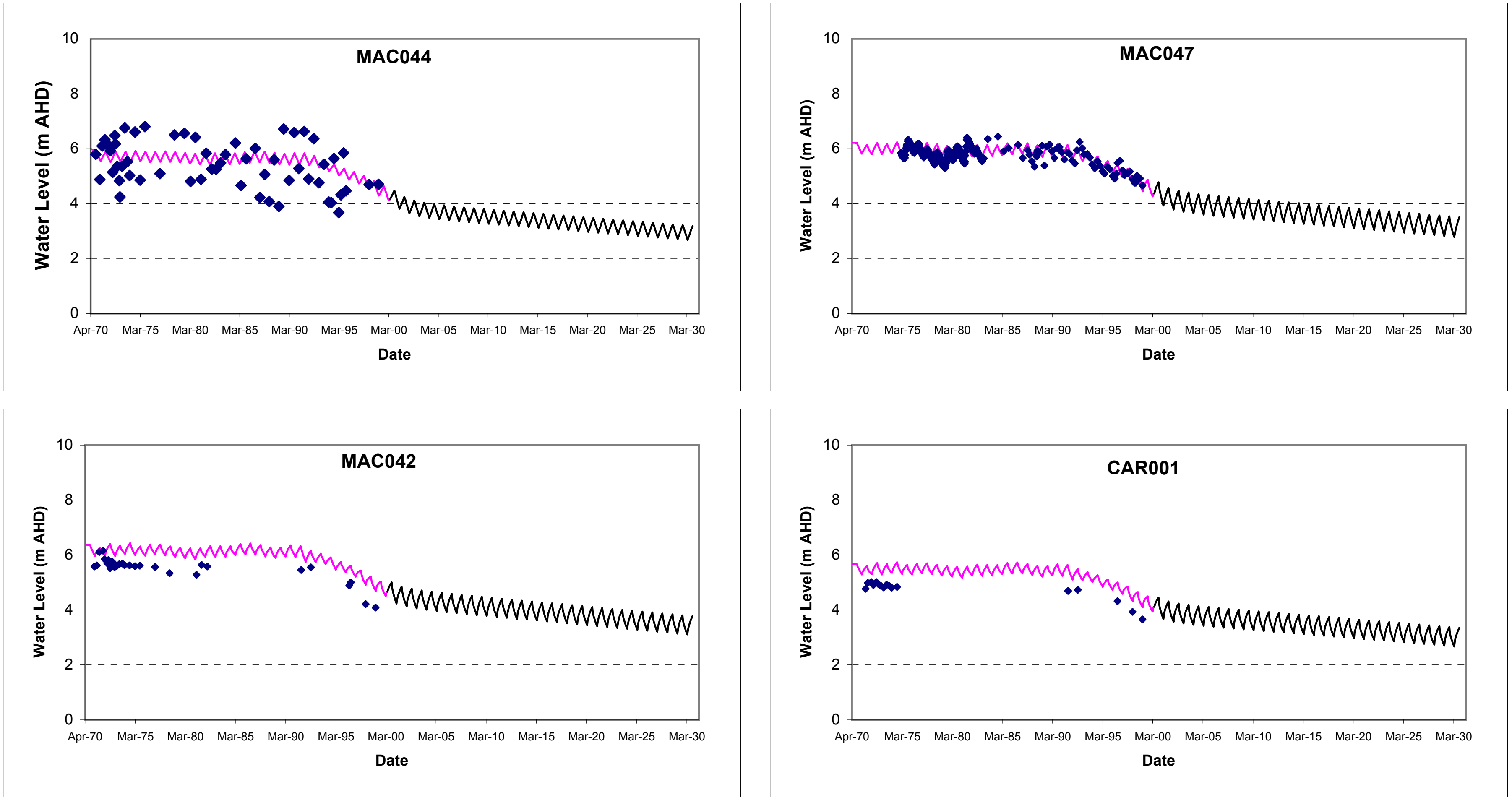




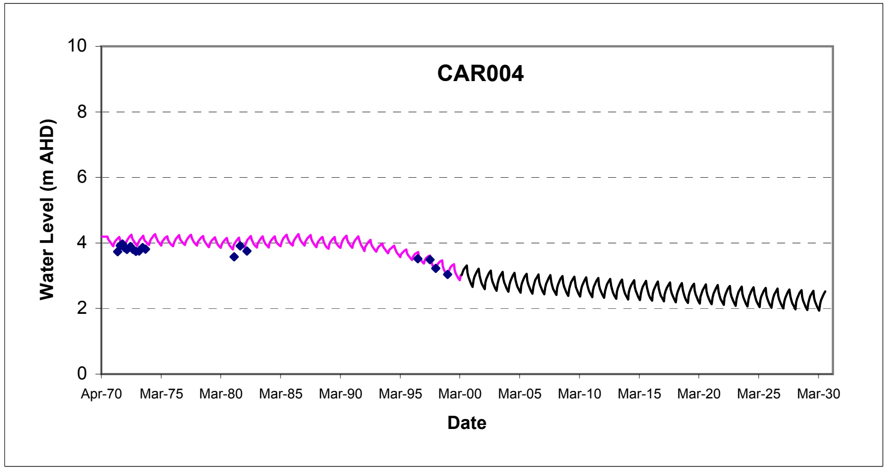


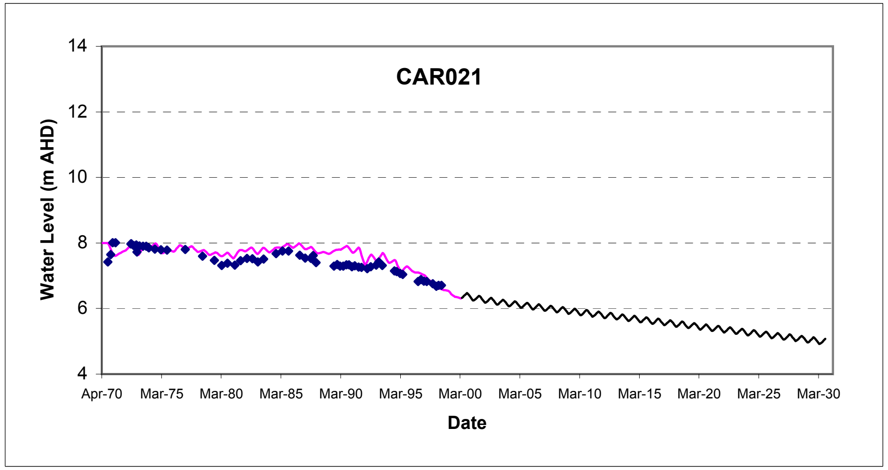


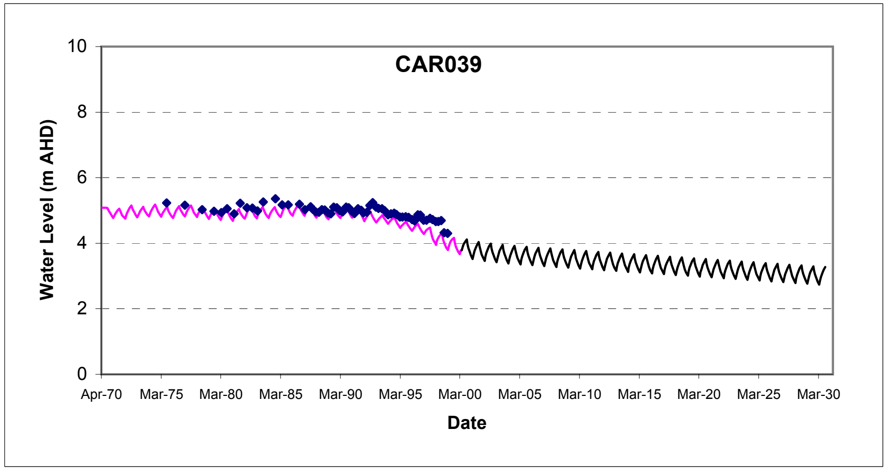
Appendix C3-4 *Hydrographs for Scenario 3 with large head decline on the northern boundary (1970-2030)*

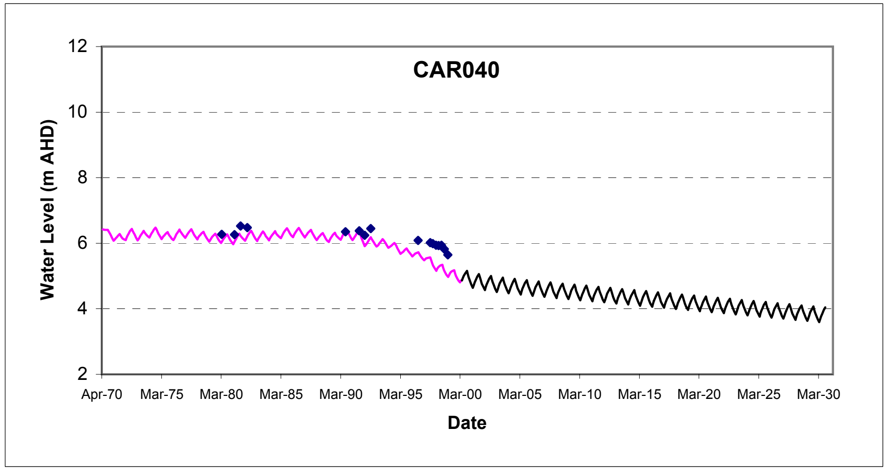


Appendix C3-5 *Hydrographs for Scenario 3 with large head decline on the northern boundary (1970-2030)*









Appendix C3-6 *Hydrographs for Scenario 3 with large head decline on the northern boundary (1970-2030)*

Appendix D1

Scenario 4: Results with a no head decline

on the northern boundary

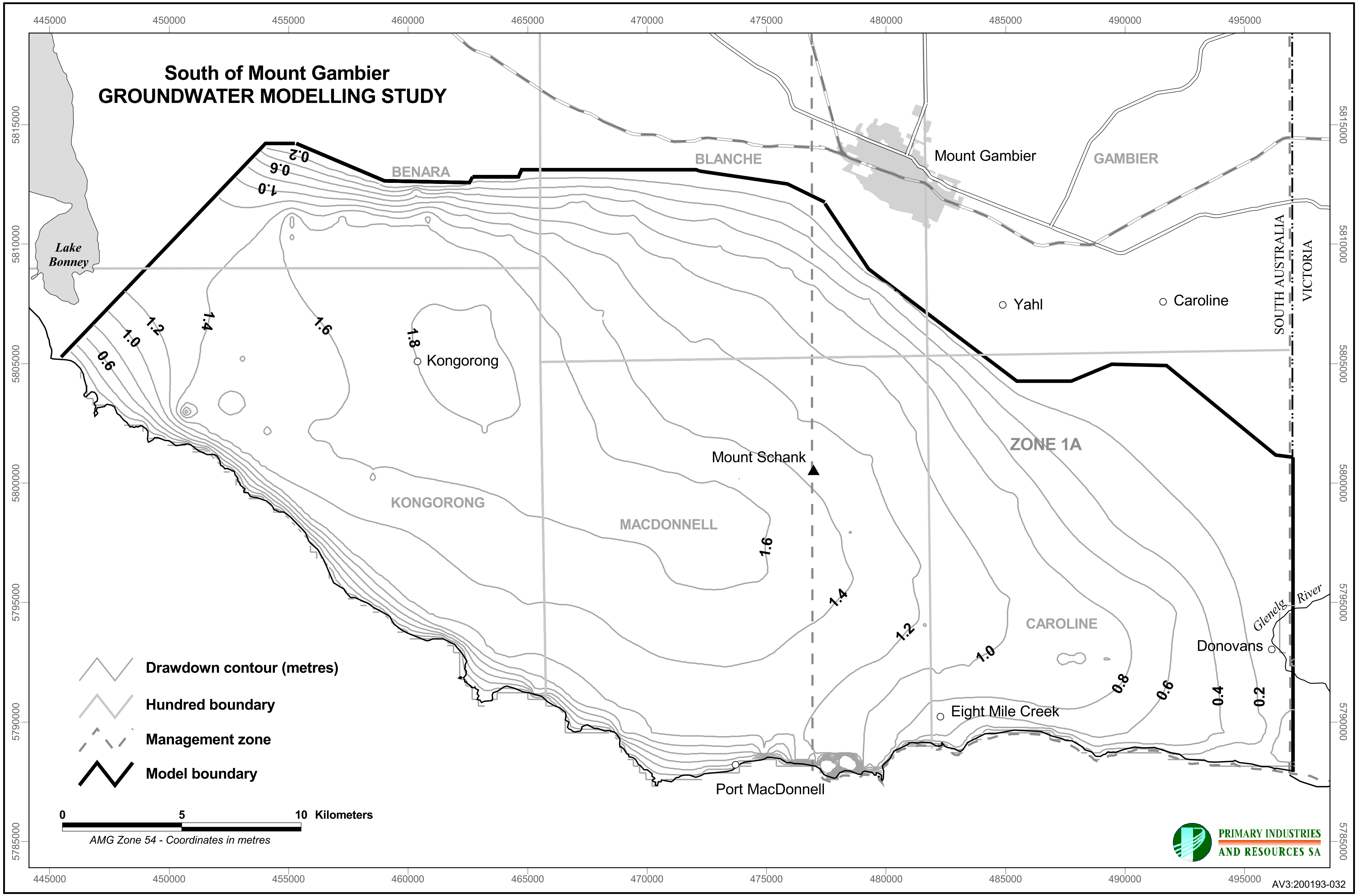


Figure D1-1 *Predicted maximum drawdown contours for scenario 4 (2000 to 2030) with no head decline on the northern boundary.*

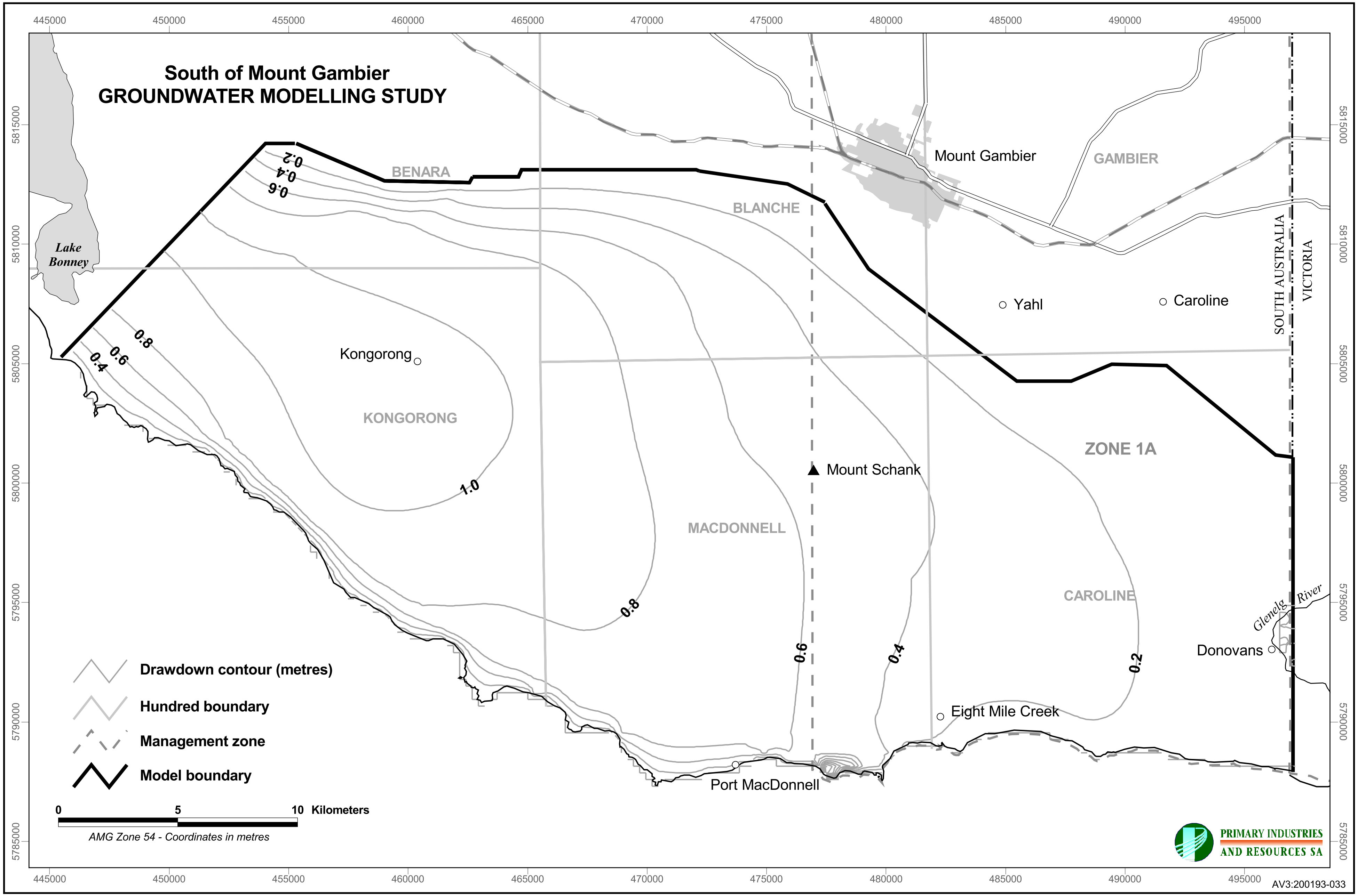
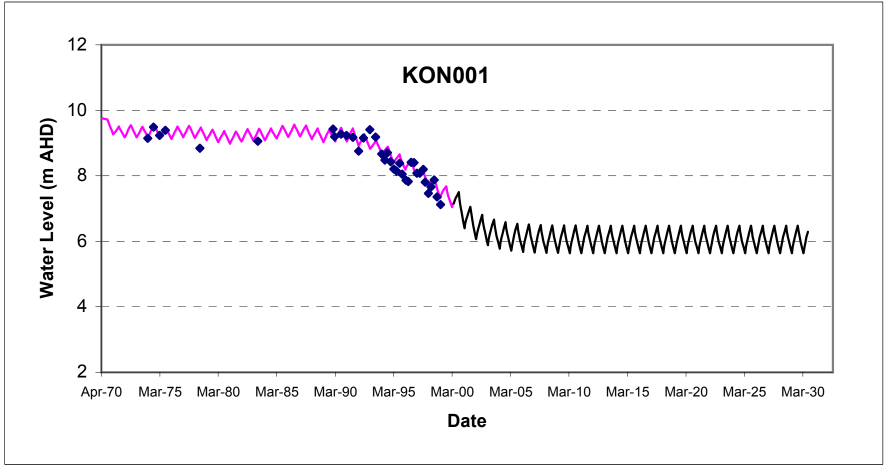
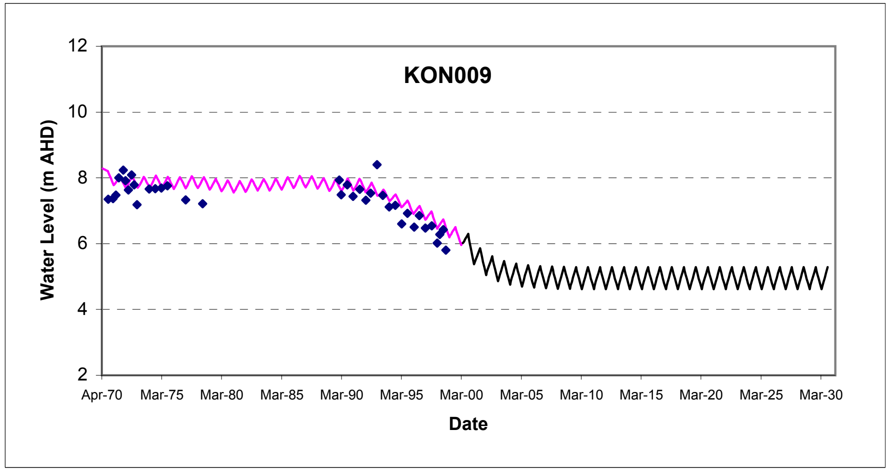
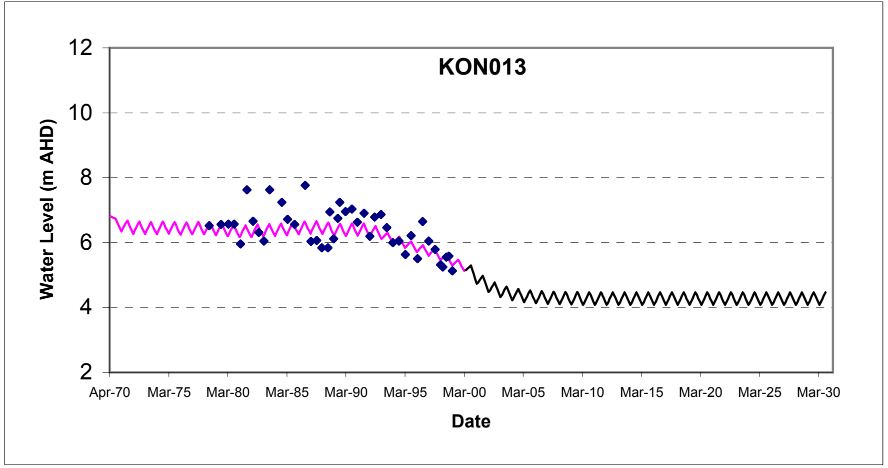
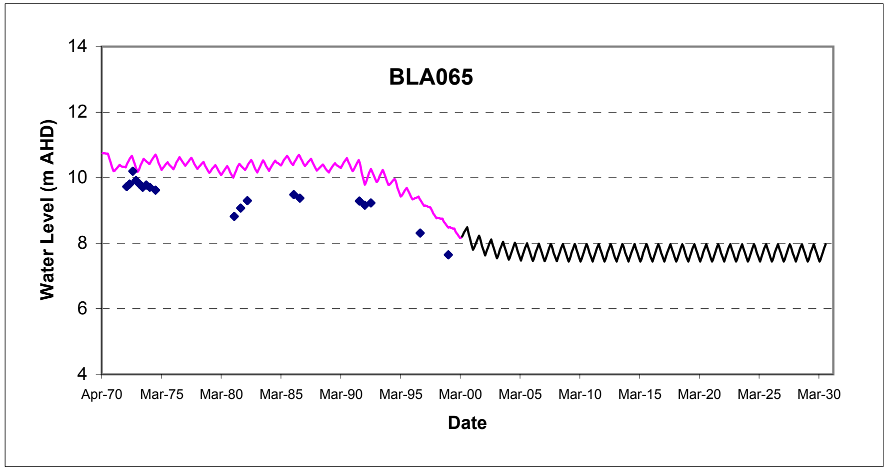


Figure D1-2 Predicted residual drawdown contours for scenario 4 (2000 to 2030) with no head decline on the northern boundary.

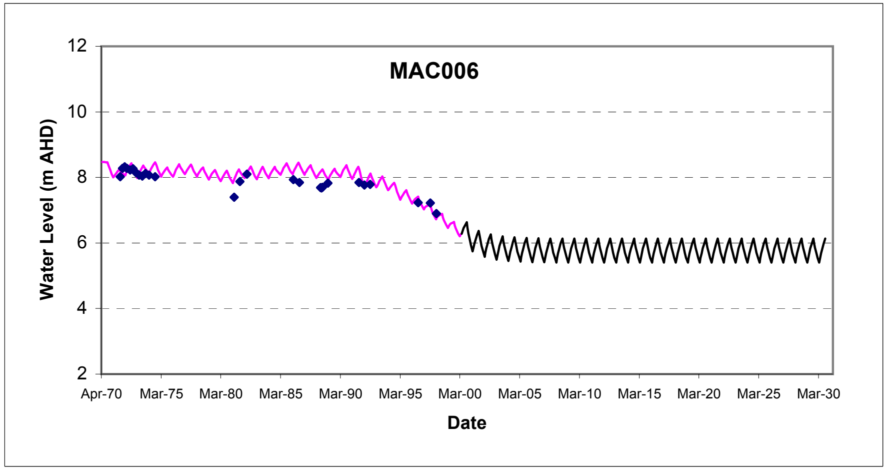


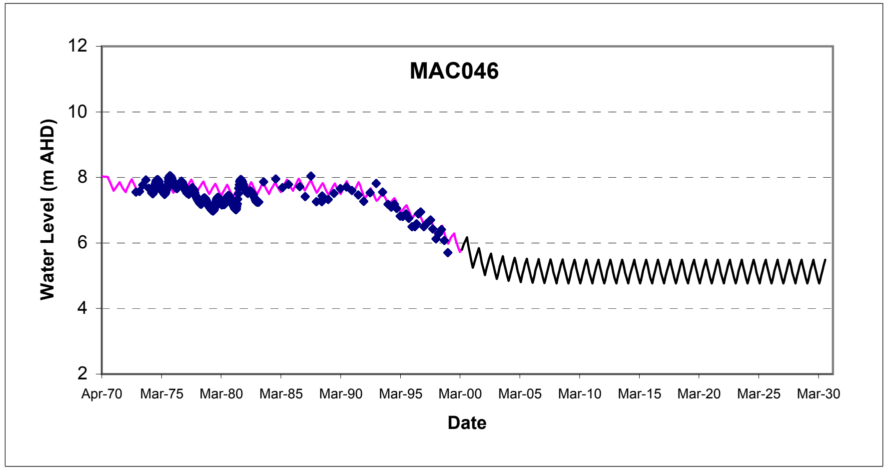


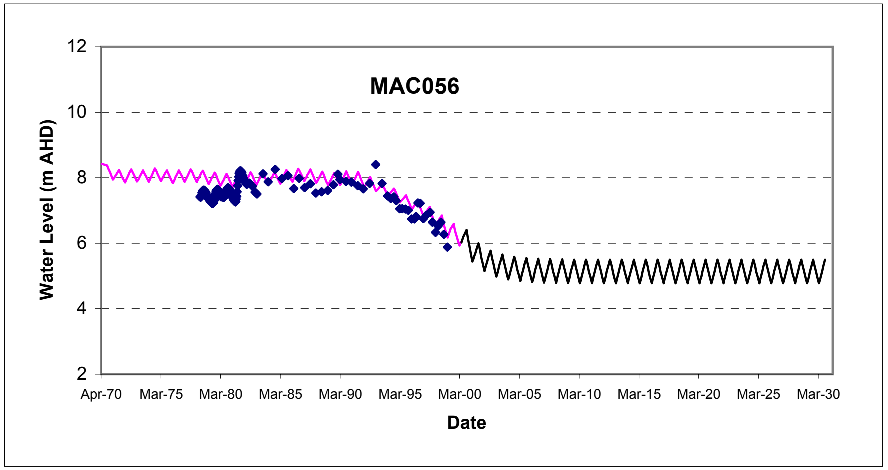


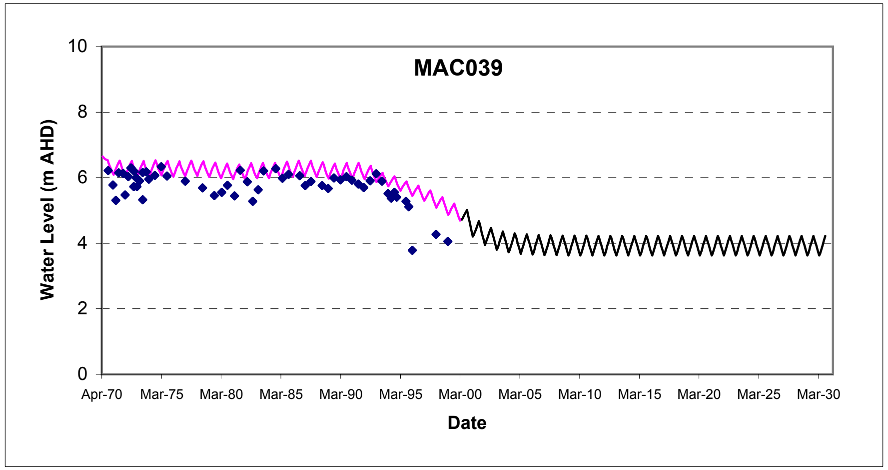


Appendix D1-3 *Hydrographs for Scenario 4 with no head decline on the northern boundary (1970-2030)*

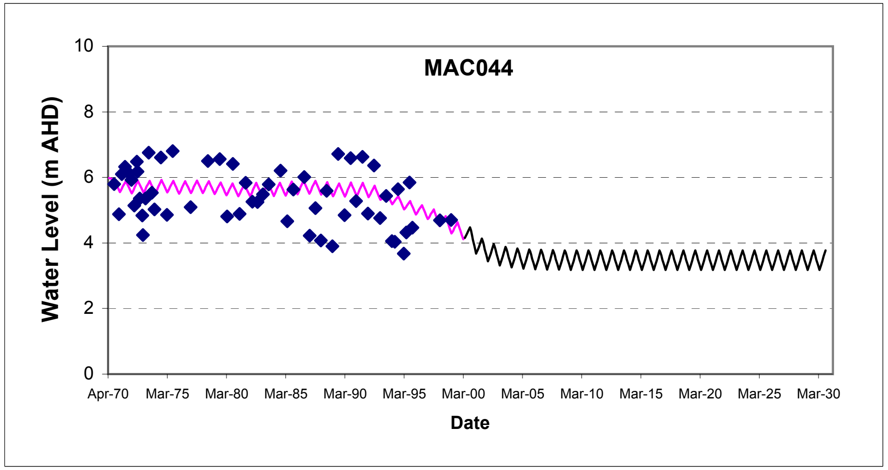


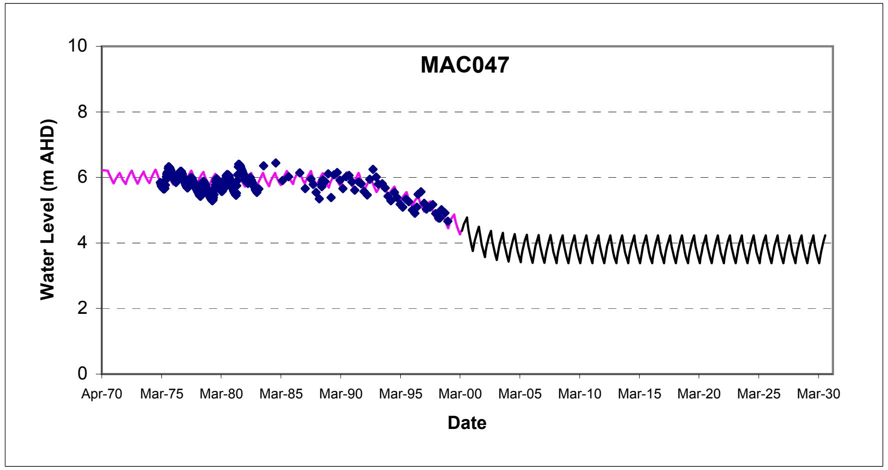


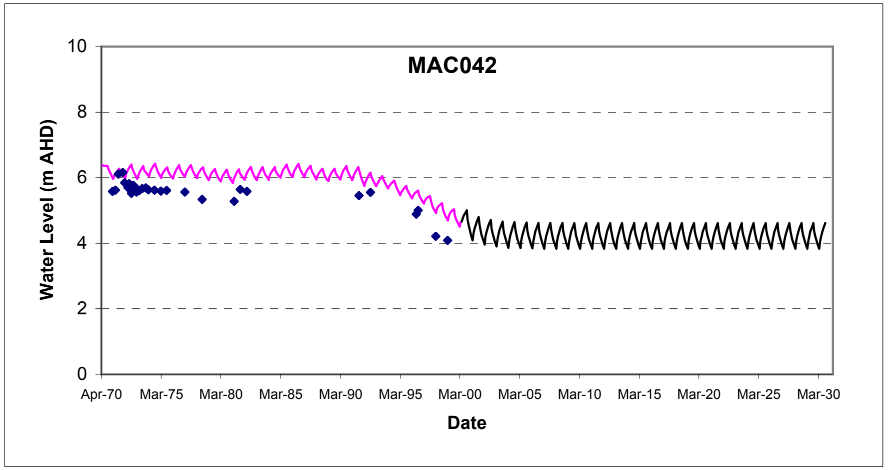


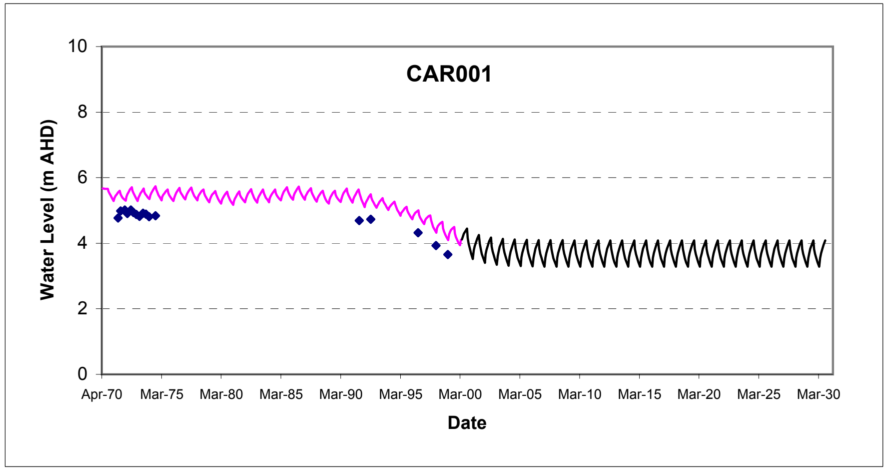


Appendix D1-4 *Hydrographs for Scenario 4 with no head decline on the northern boundary (1970-2030)*

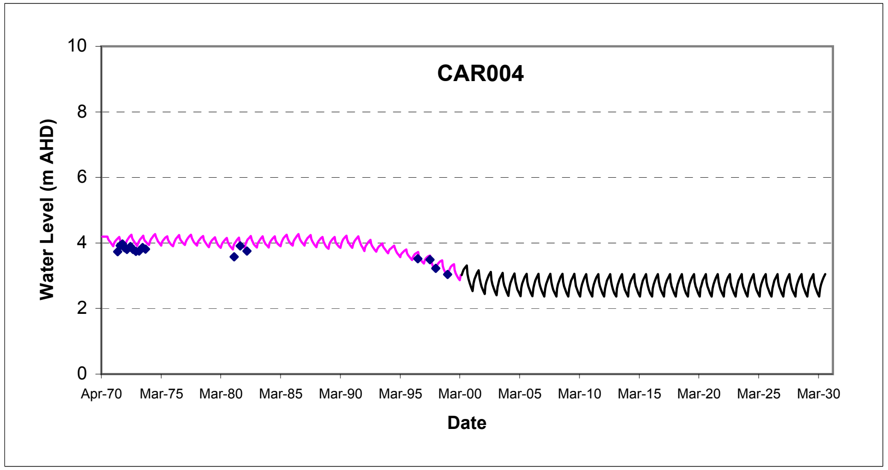


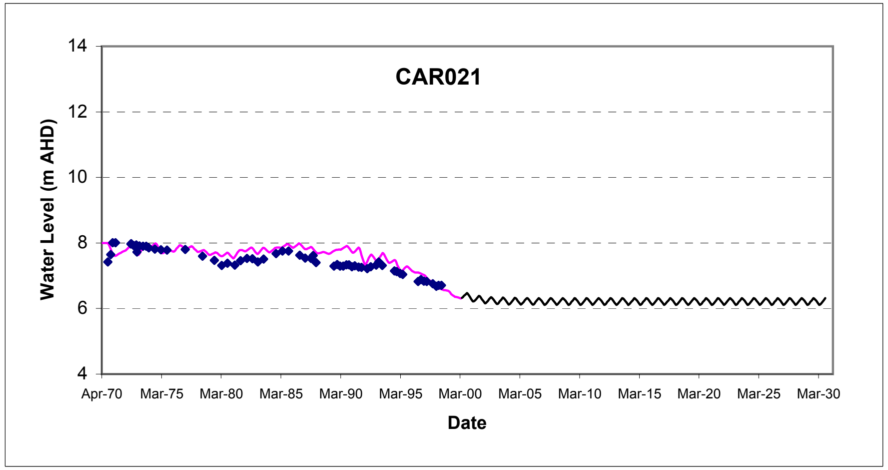


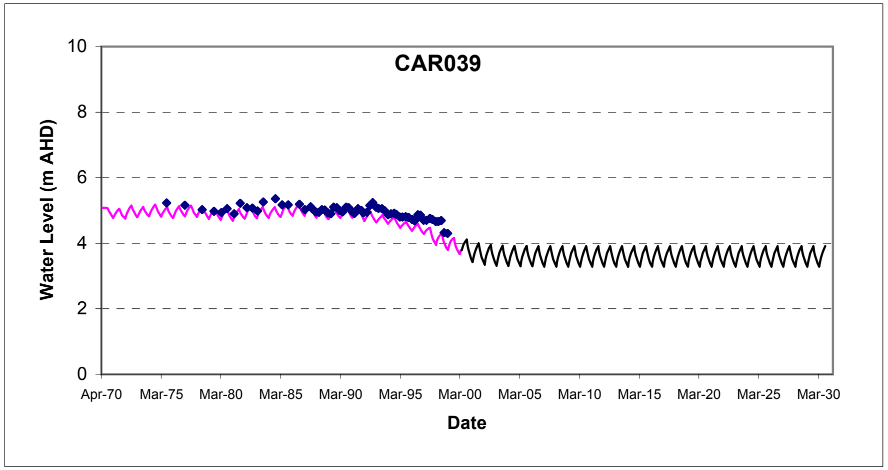


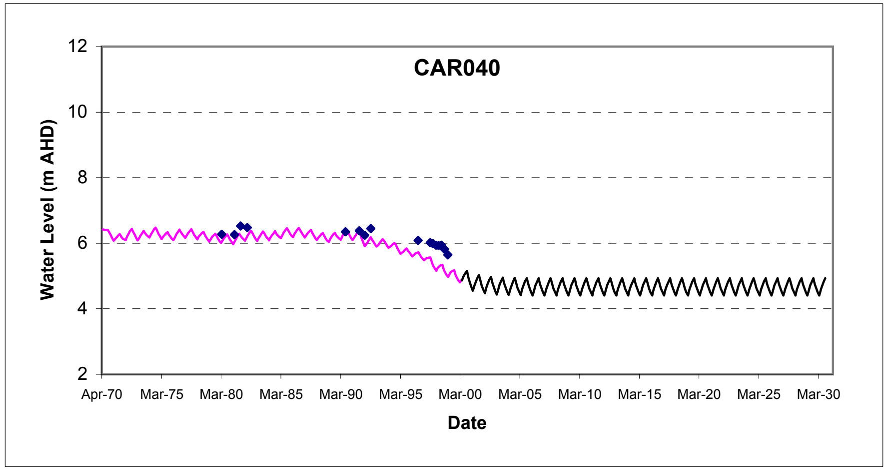


Appendix D1-5 *Hydrographs for Scenario 4 with no head decline on the northern boundary (1970-2030)*









Appendix D1-6 *Hydrographs for Scenario 4 with no head decline on the northern boundary (1970-2030)*

Appendix D2

Scenario 4: Results with a no head decline

on the northern boundary

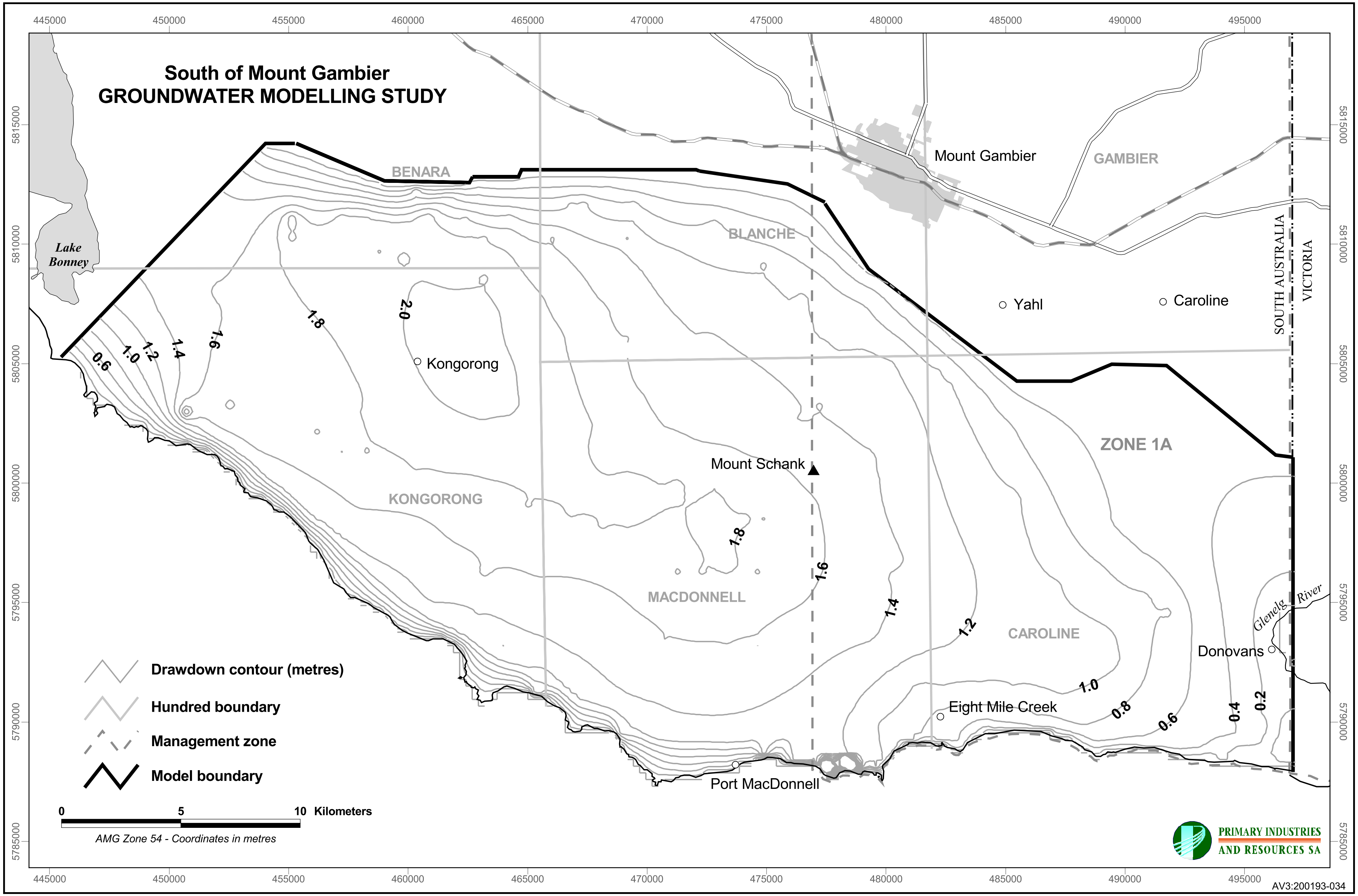


Figure D2-1 *Predicted maximum drawdown contours for scenario 4 (2000 to 2030) with small head decline on the northern boundary.*

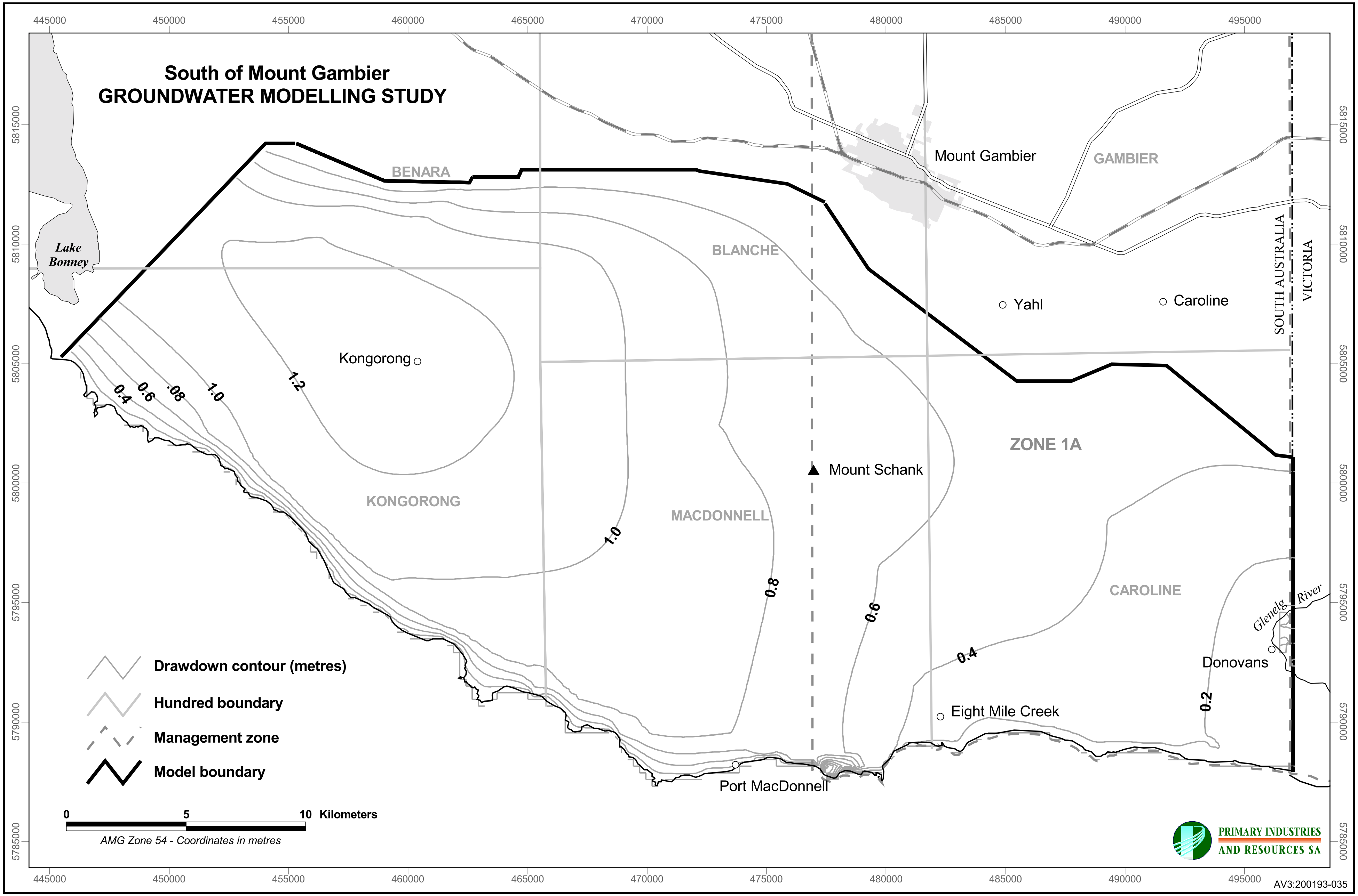
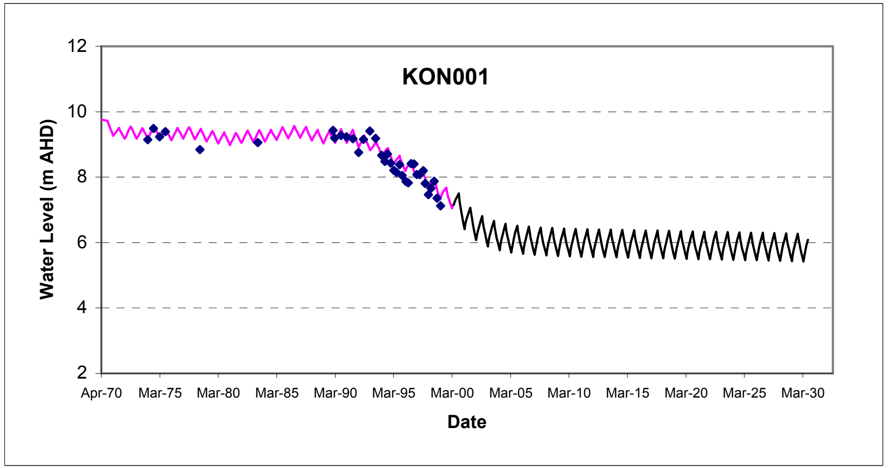
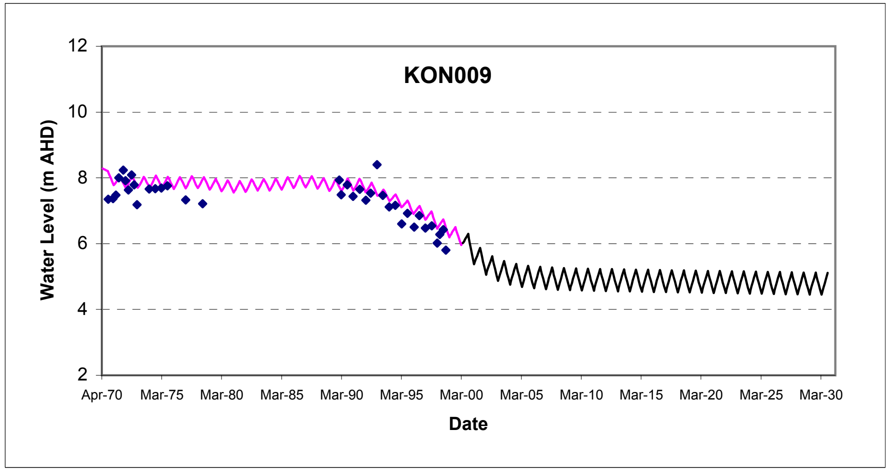
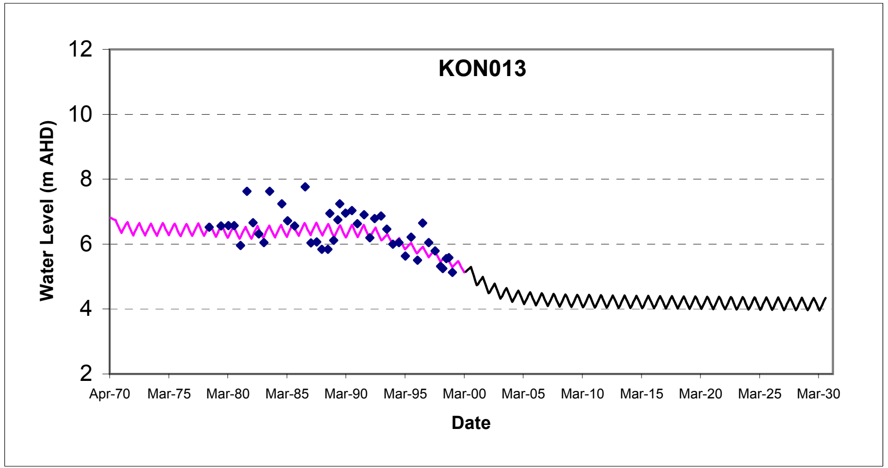
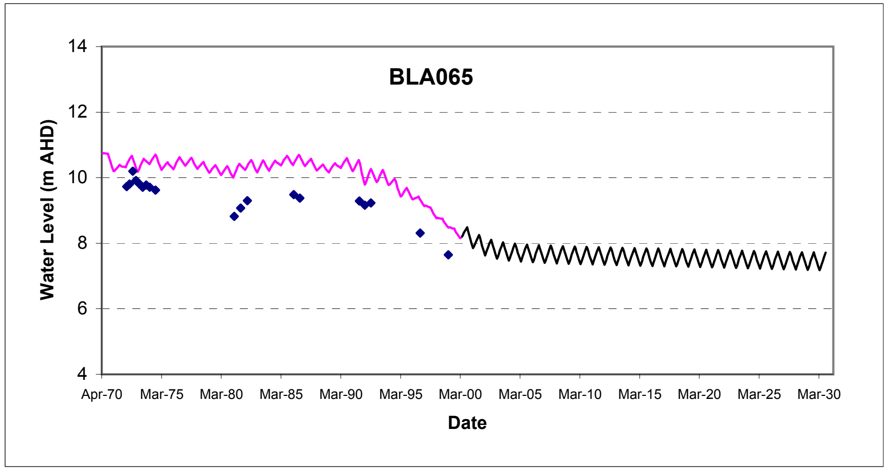


Figure D2-2 *Predicted residual drawdown contours for scenario 4 (2000 to 2030) with small head decline on the northern boundary.*

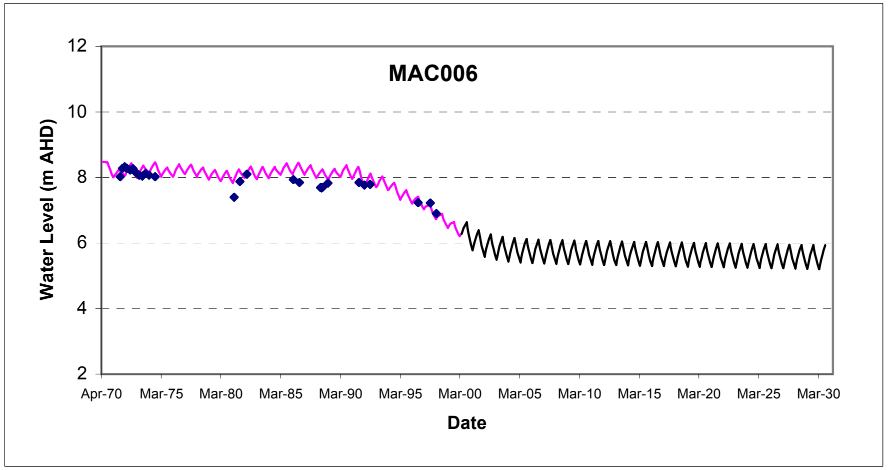


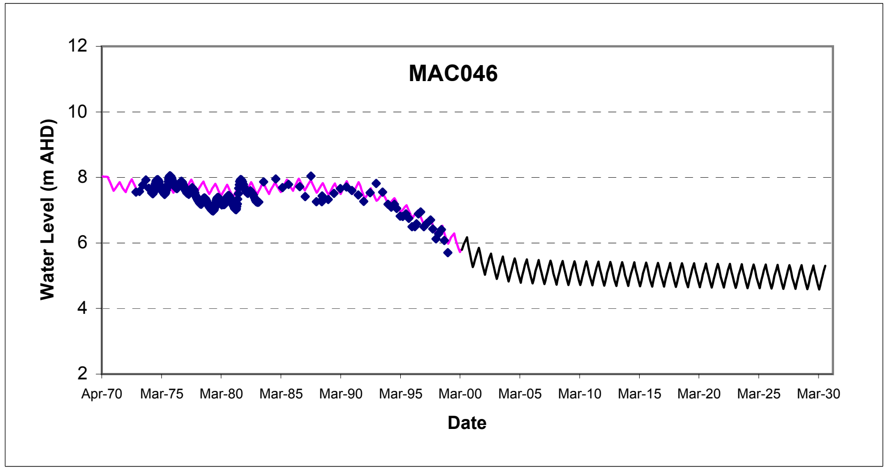


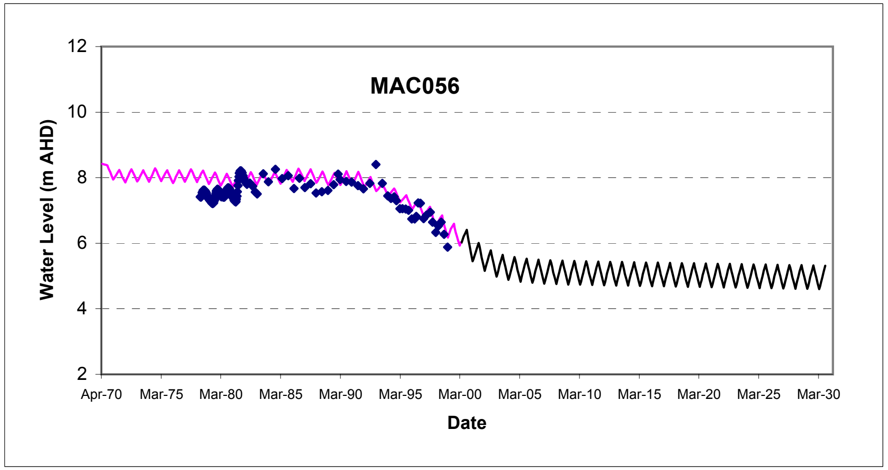


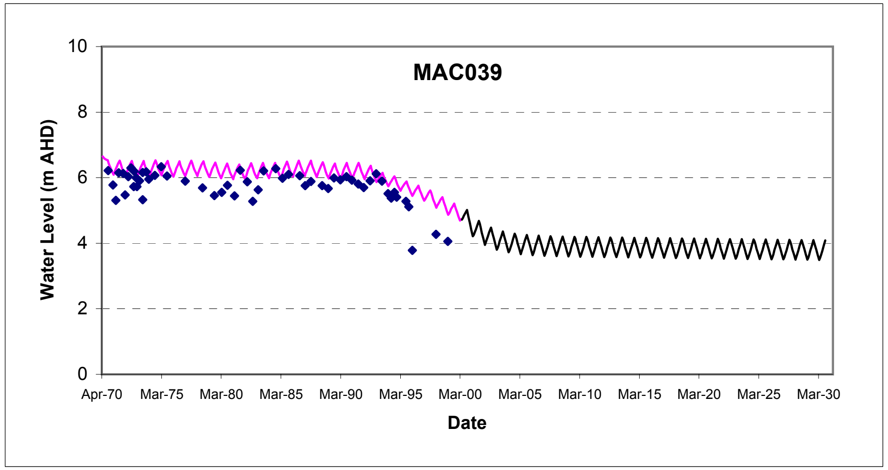


Appendix D2-3 *Hydrographs for Scenario 4 with small head decline on the northern boundary (1970-2030)*

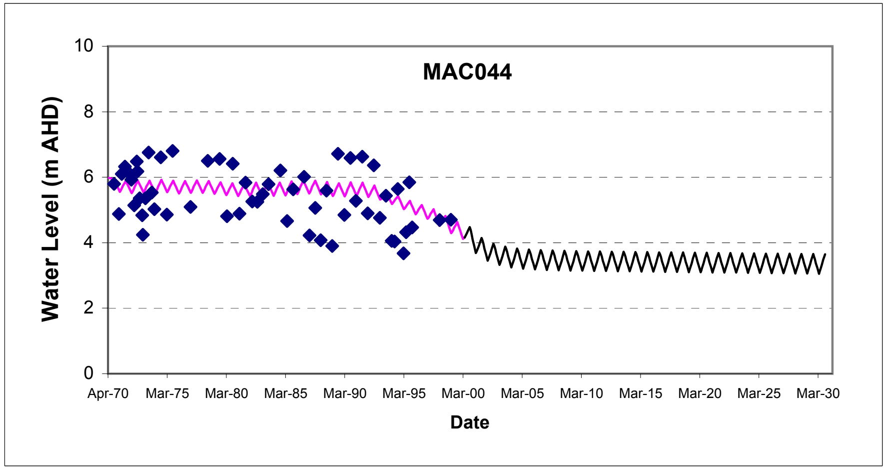


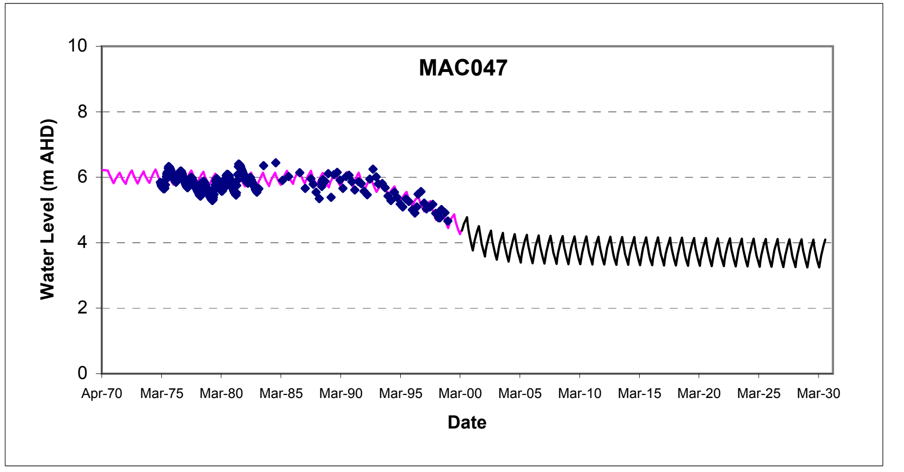


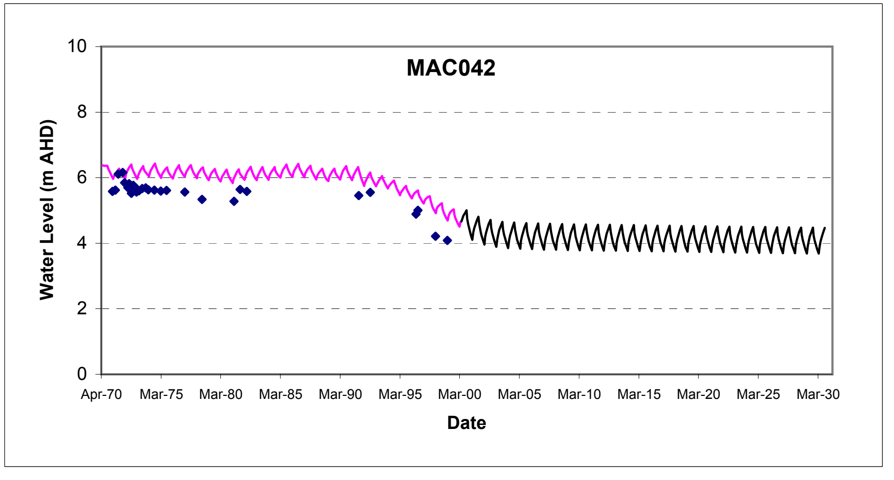


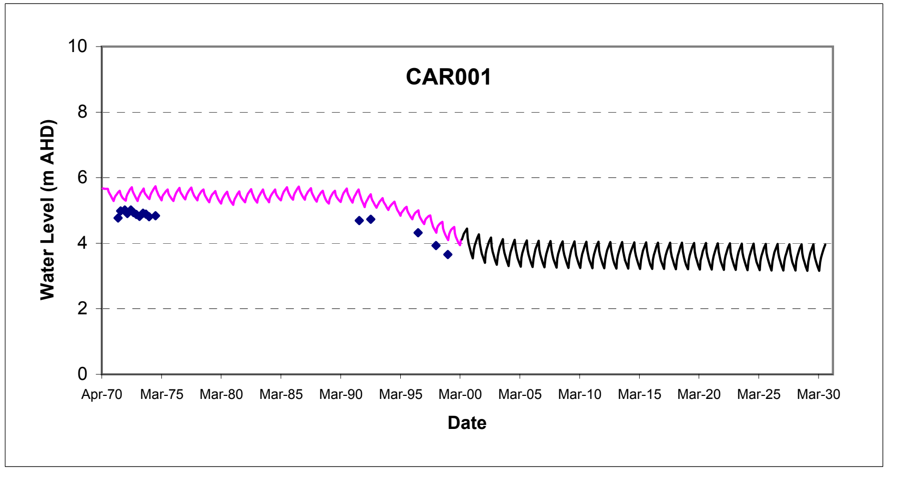


Appendix D2-4 *Hydrographs for Scenario 4 with small head decline on the northern boundary (1970-2030)*

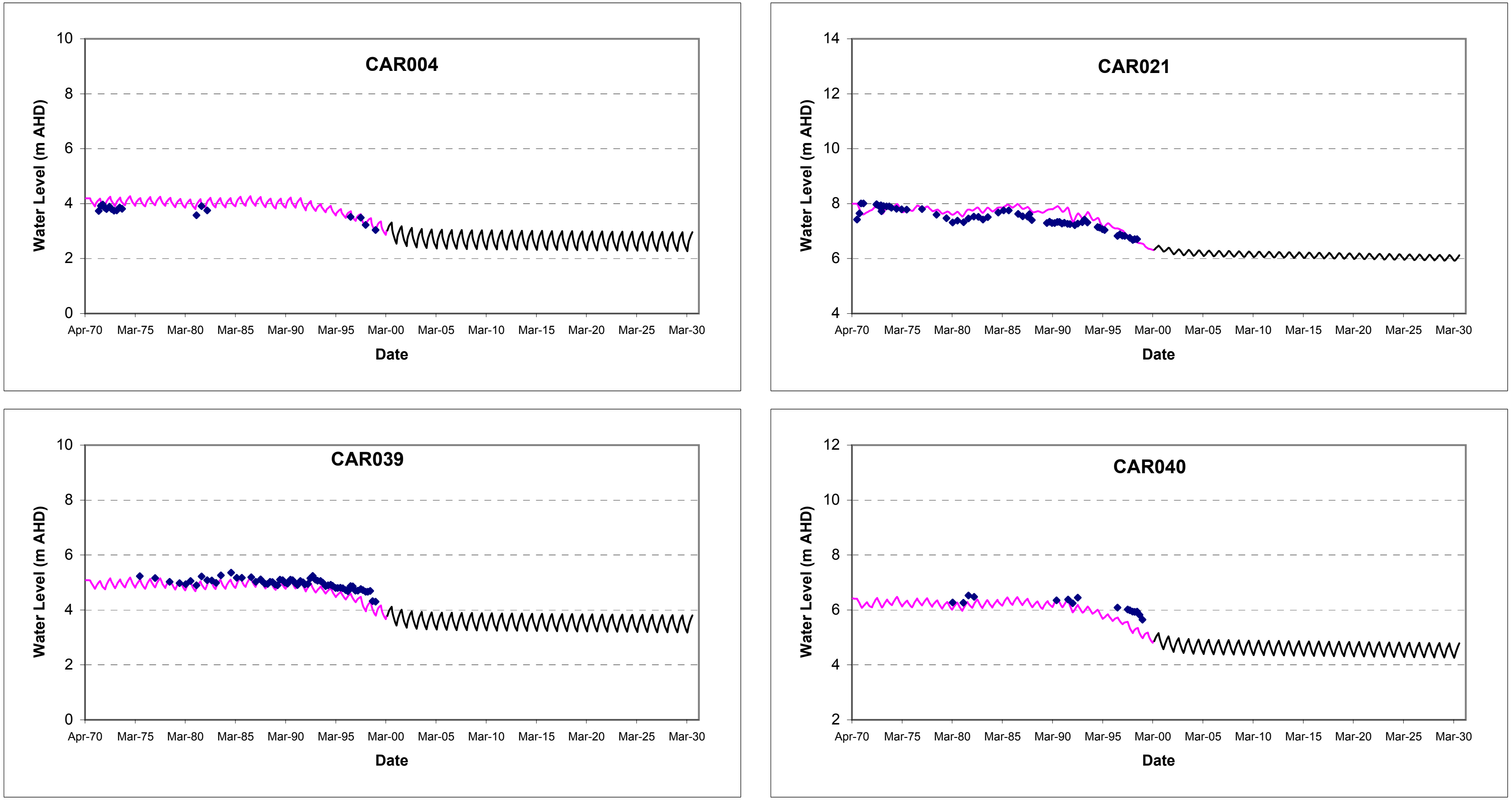








Appendix D2-5 *Hydrographs for Scenario 4 with small head decline on the northern boundary (1970-2030)*



Appendix D2-6 *Hydrographs for Scenario 4 with small head decline on the northern boundary (1970-2030)*

Appendix D3

Scenario 4: Results with a large head decline

on the northern boundary

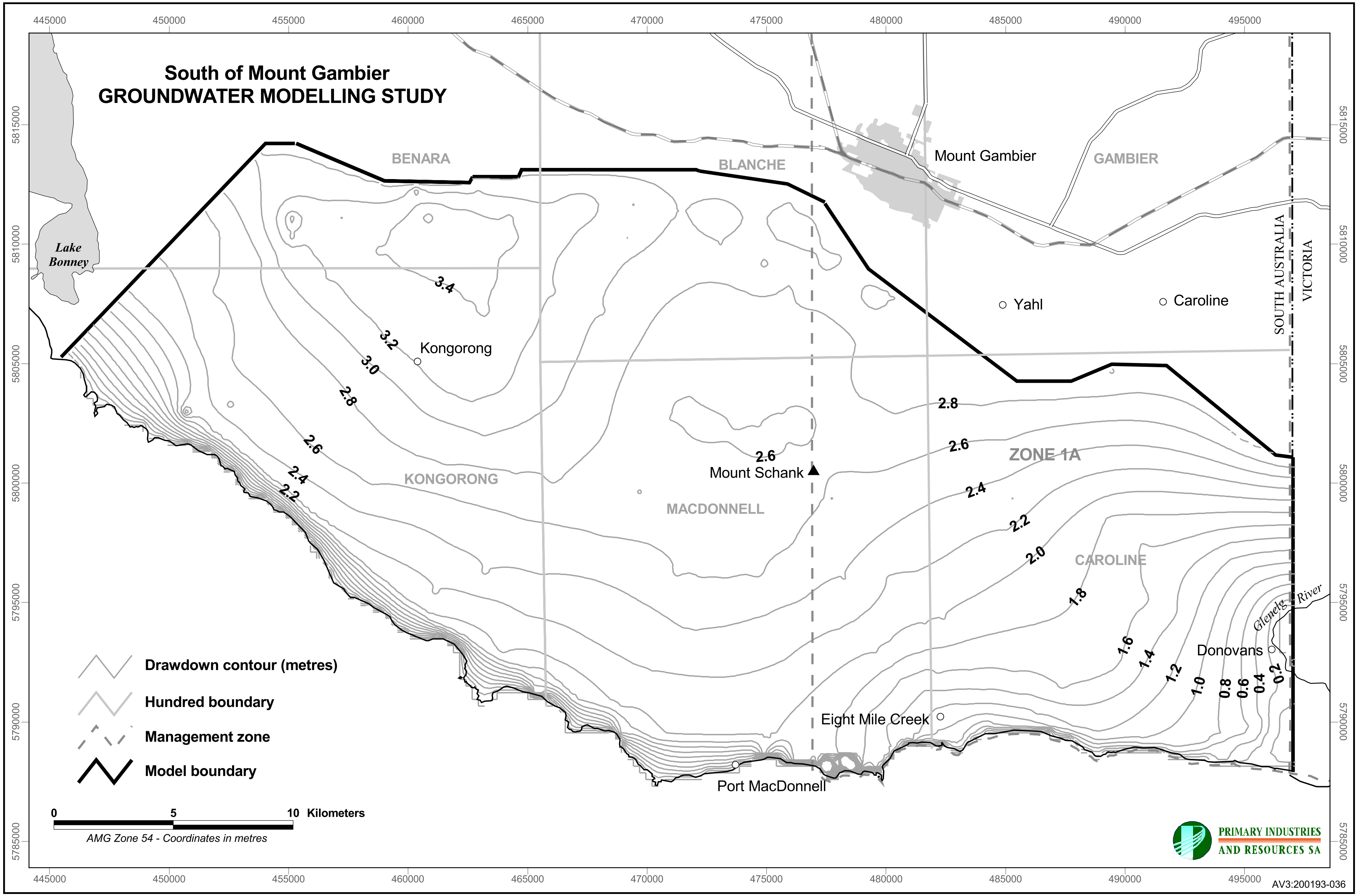


Figure D3-1 *Predicted maximum drawdown contours for scenario 4 (2000 to 2030) with large head decline on the northern boundary.*

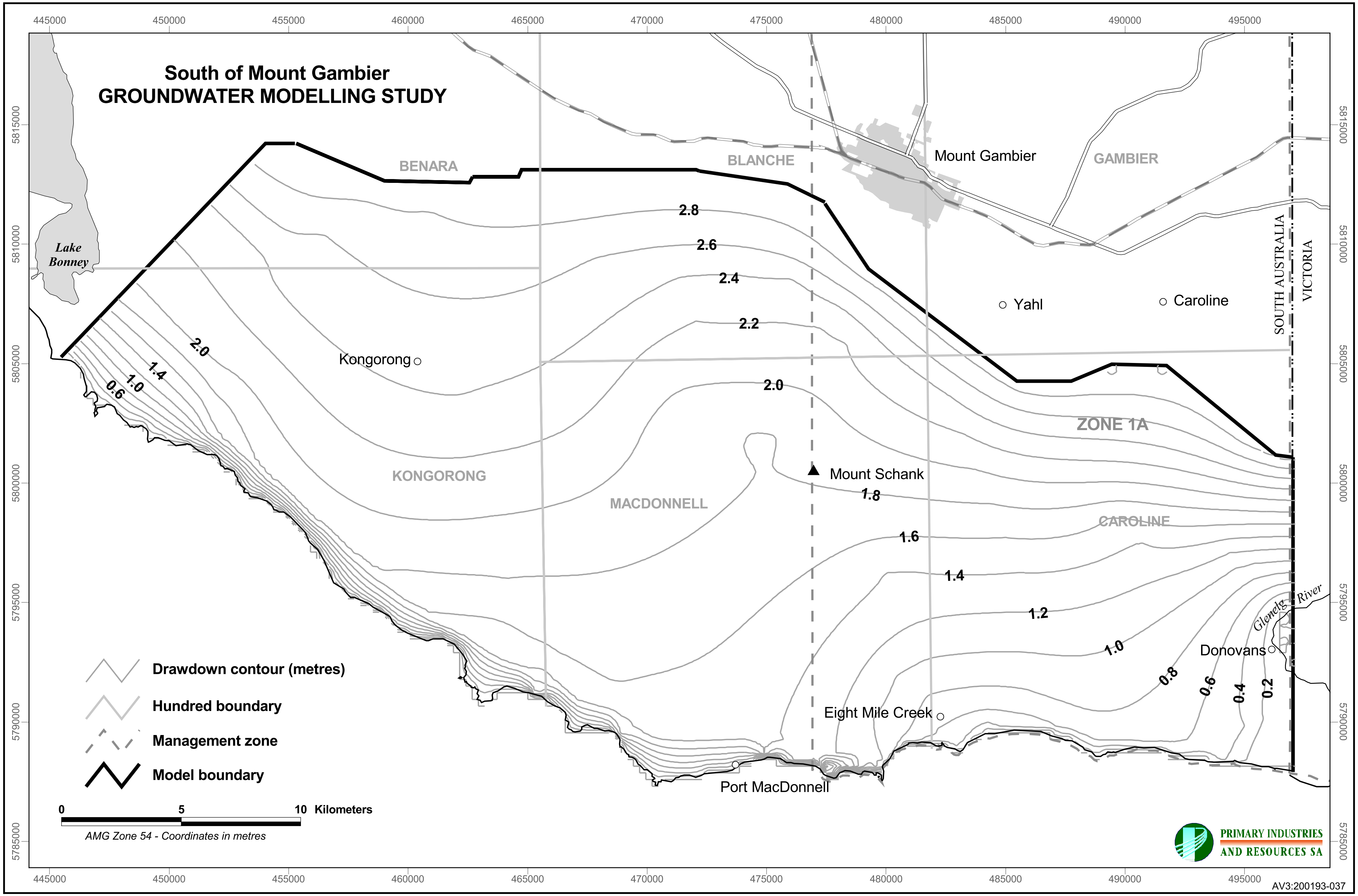
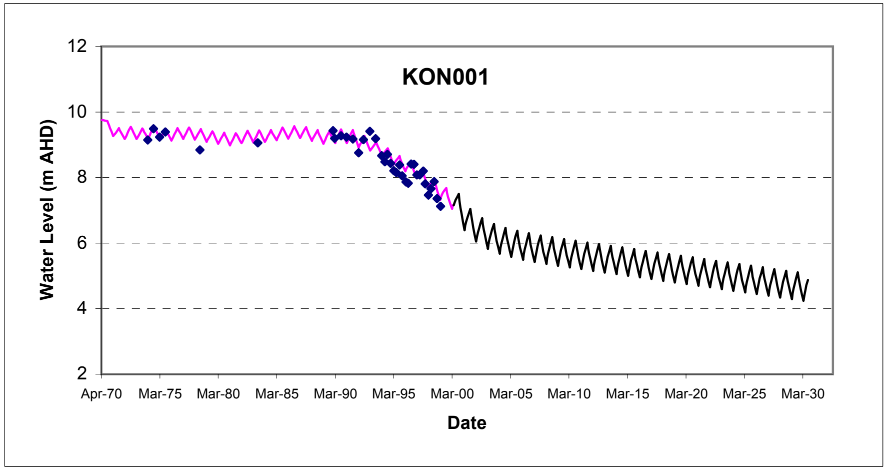
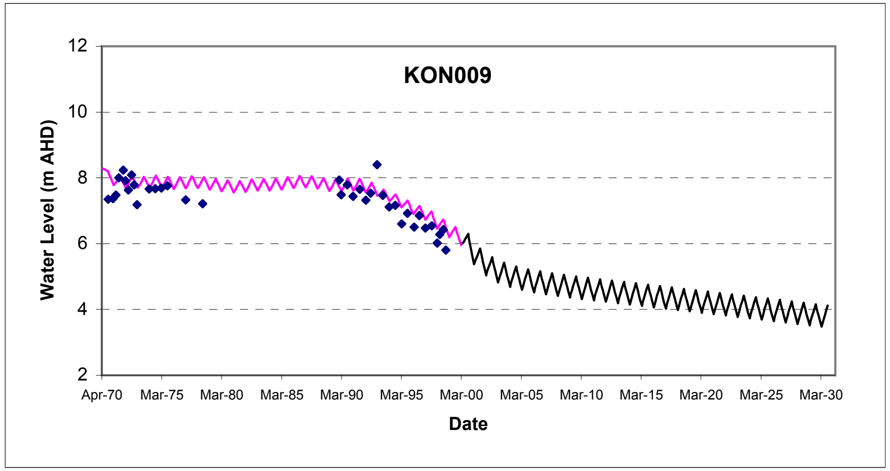
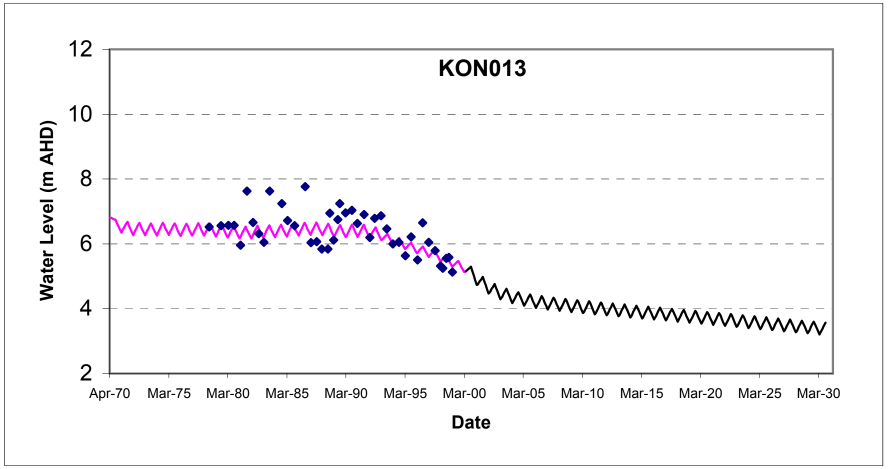
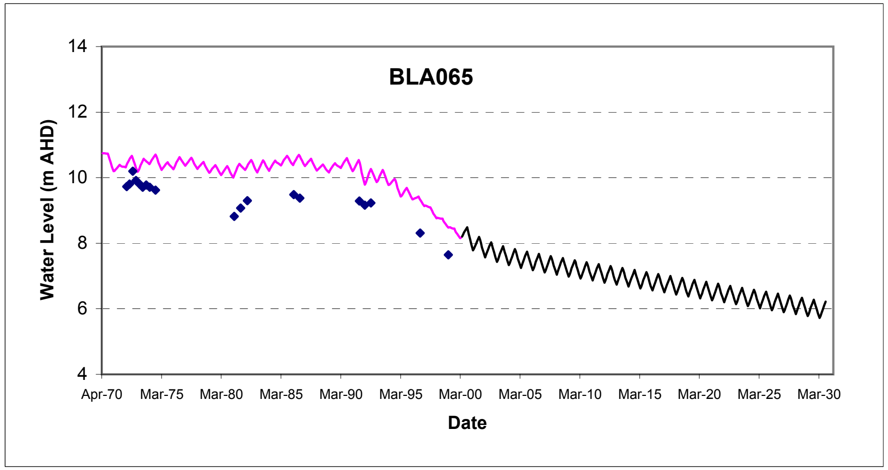


Figure D3-2 *Predicted residual drawdown contours for scenario 4 (2000 to 2030) with large head decline on the northern boundary.*

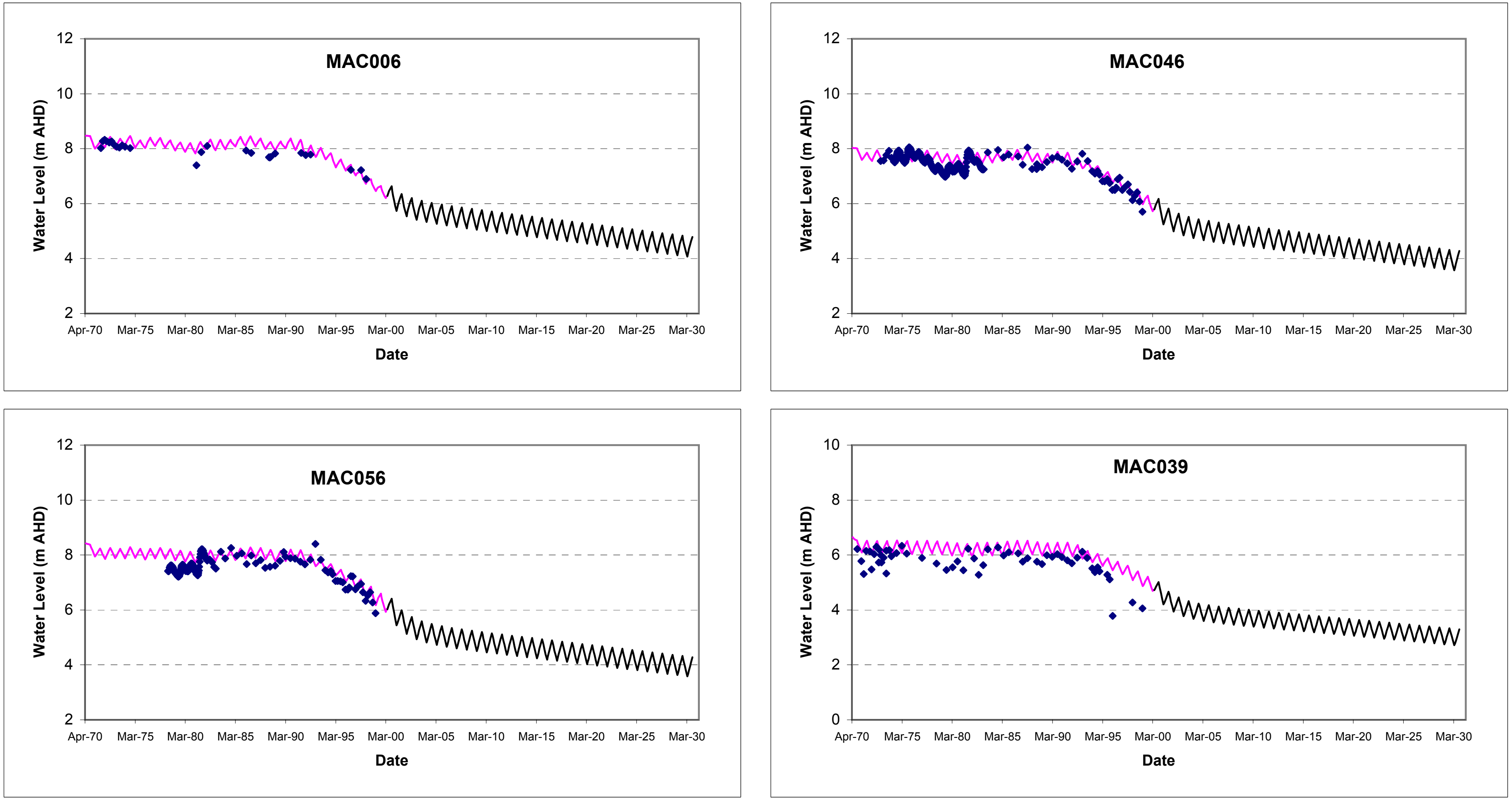




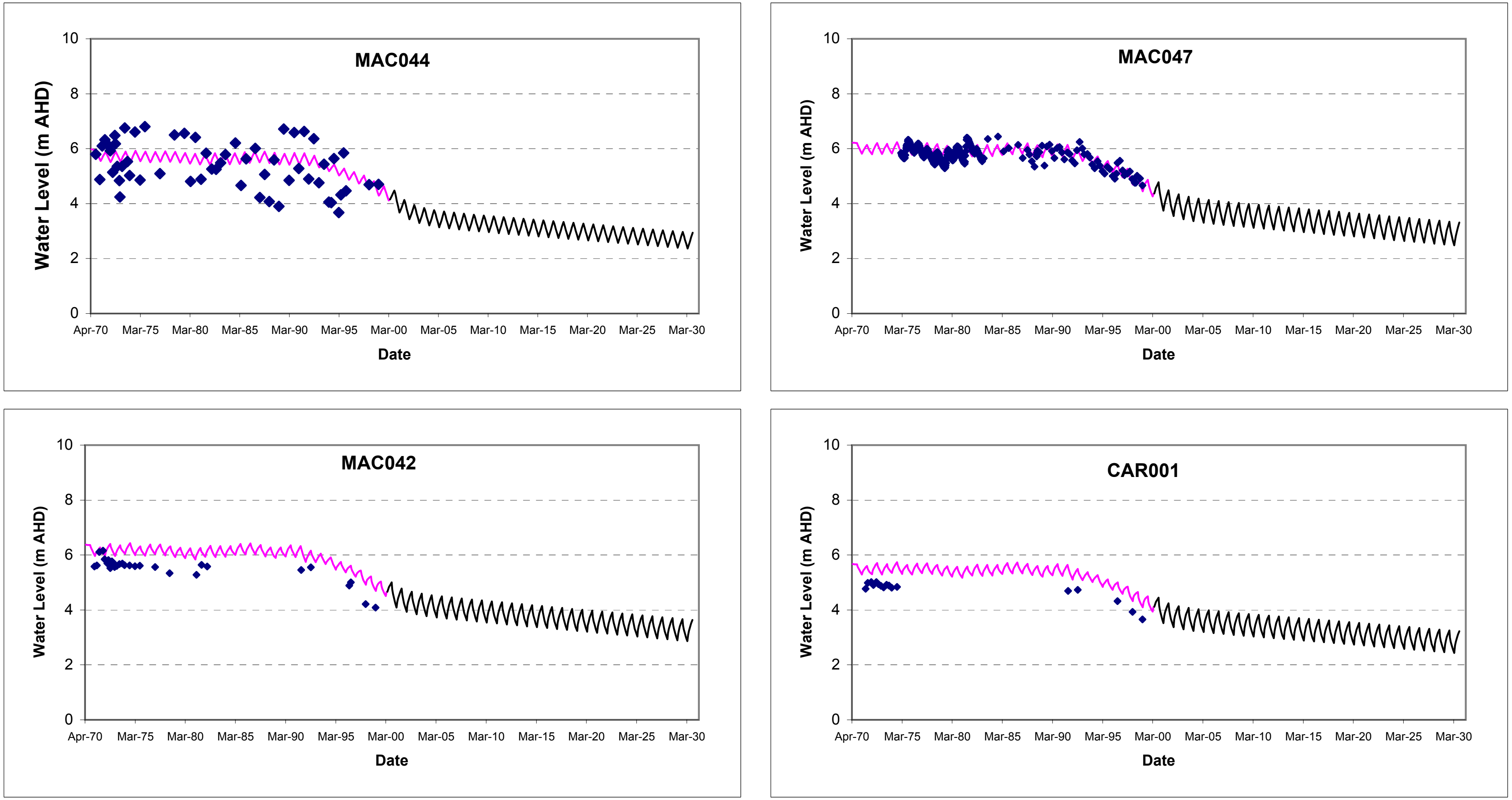




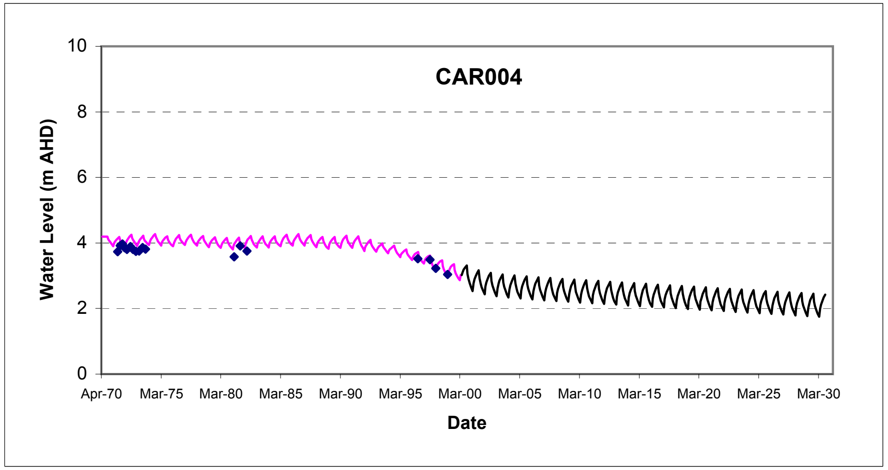
Appendix D3-3 *Hydrographs for Scenario 4 with large head decline on the northern boundary (1970-2030)*

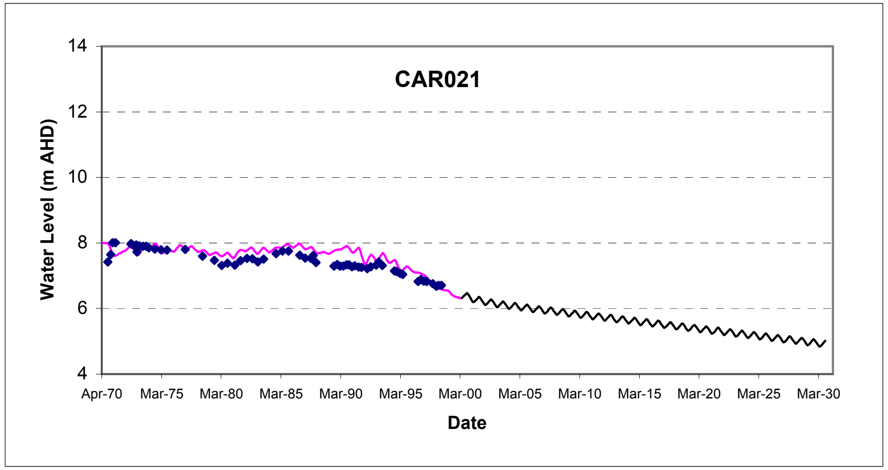


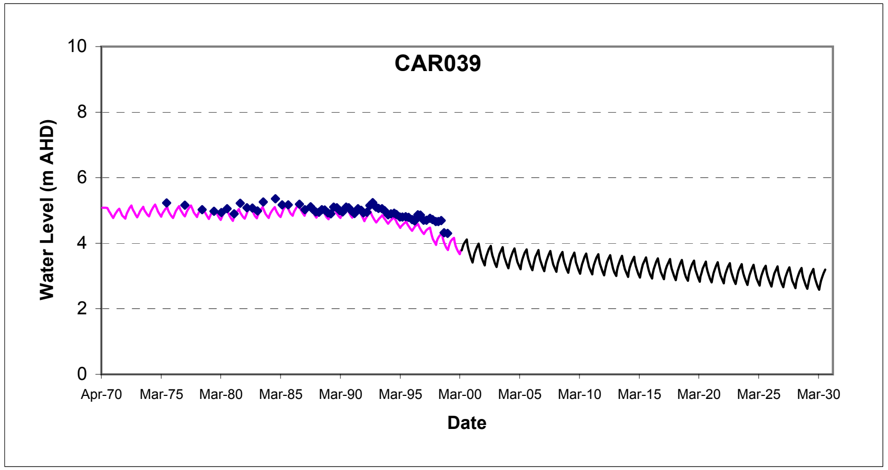
Appendix D3-4 *Hydrographs for Scenario 4 with large head decline on the northern boundary (1970-2030)*

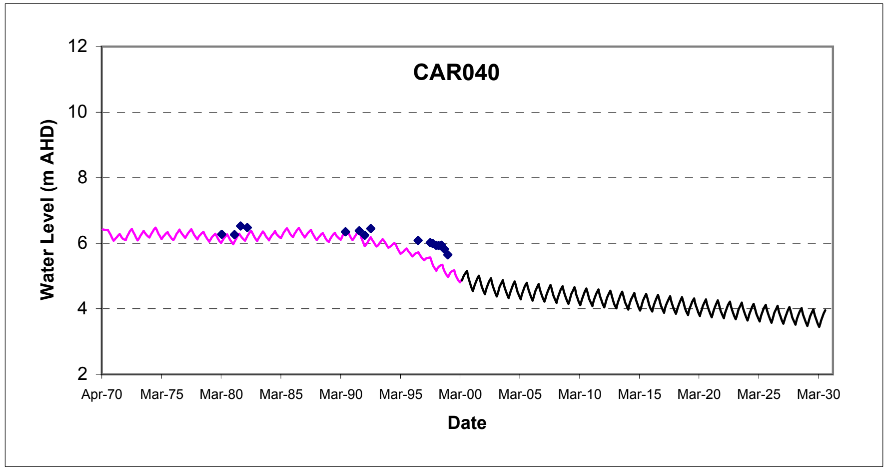


Appendix D3-5 *Hydrographs for Scenario 4 with large head decline on the northern boundary (1970-2030)*









Appendix D3-6 *Hydrographs for Scenario 4 with large head decline on the northern boundary (1970-2030)*

Appendix E1

Scenario 5: Results with a no head decline

on the northern boundary

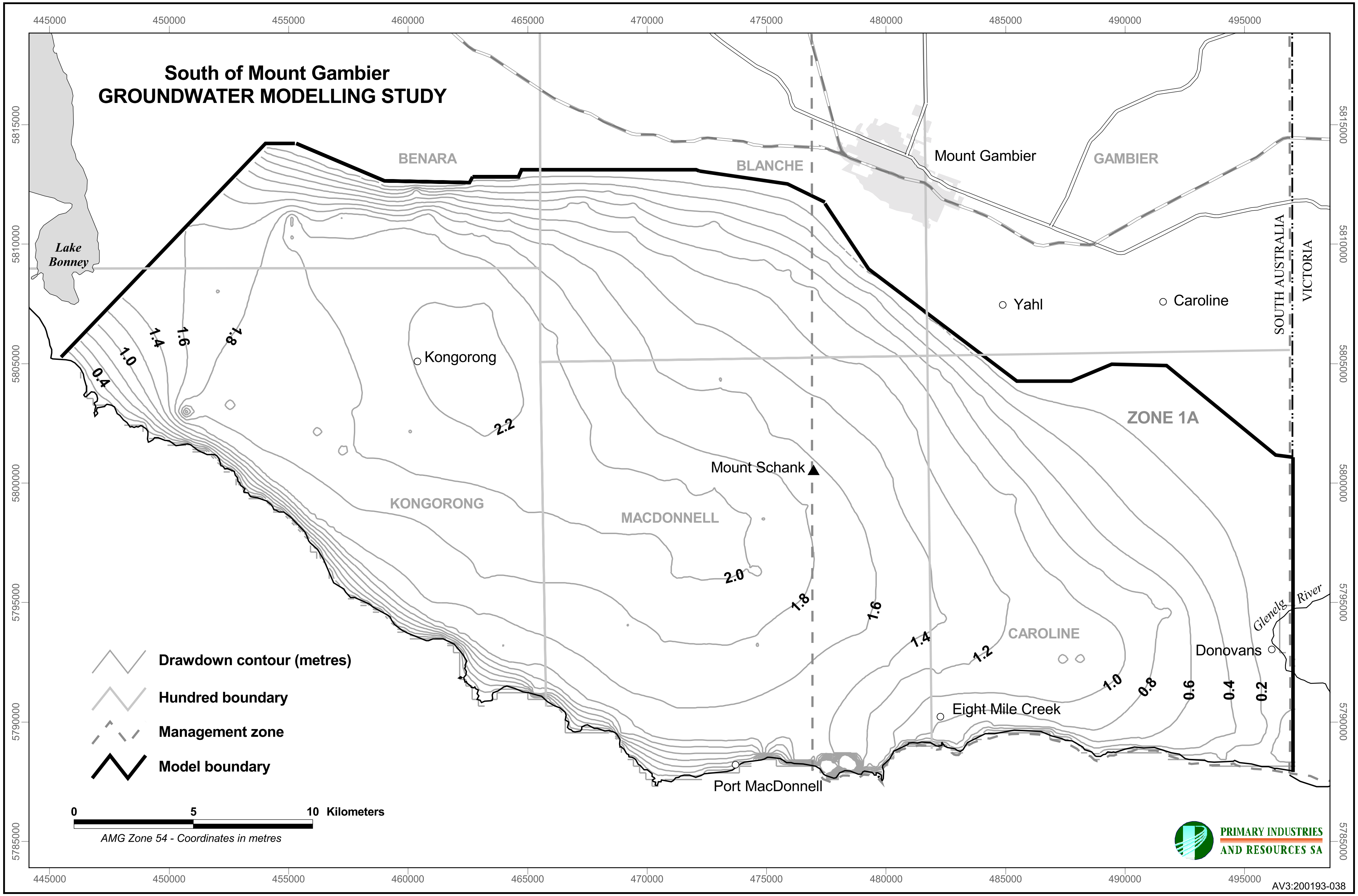


Figure E1-1 *Predicted maximum drawdown contours for scenario 5 (2000 to 2030) with no head decline on the northern boundary.*

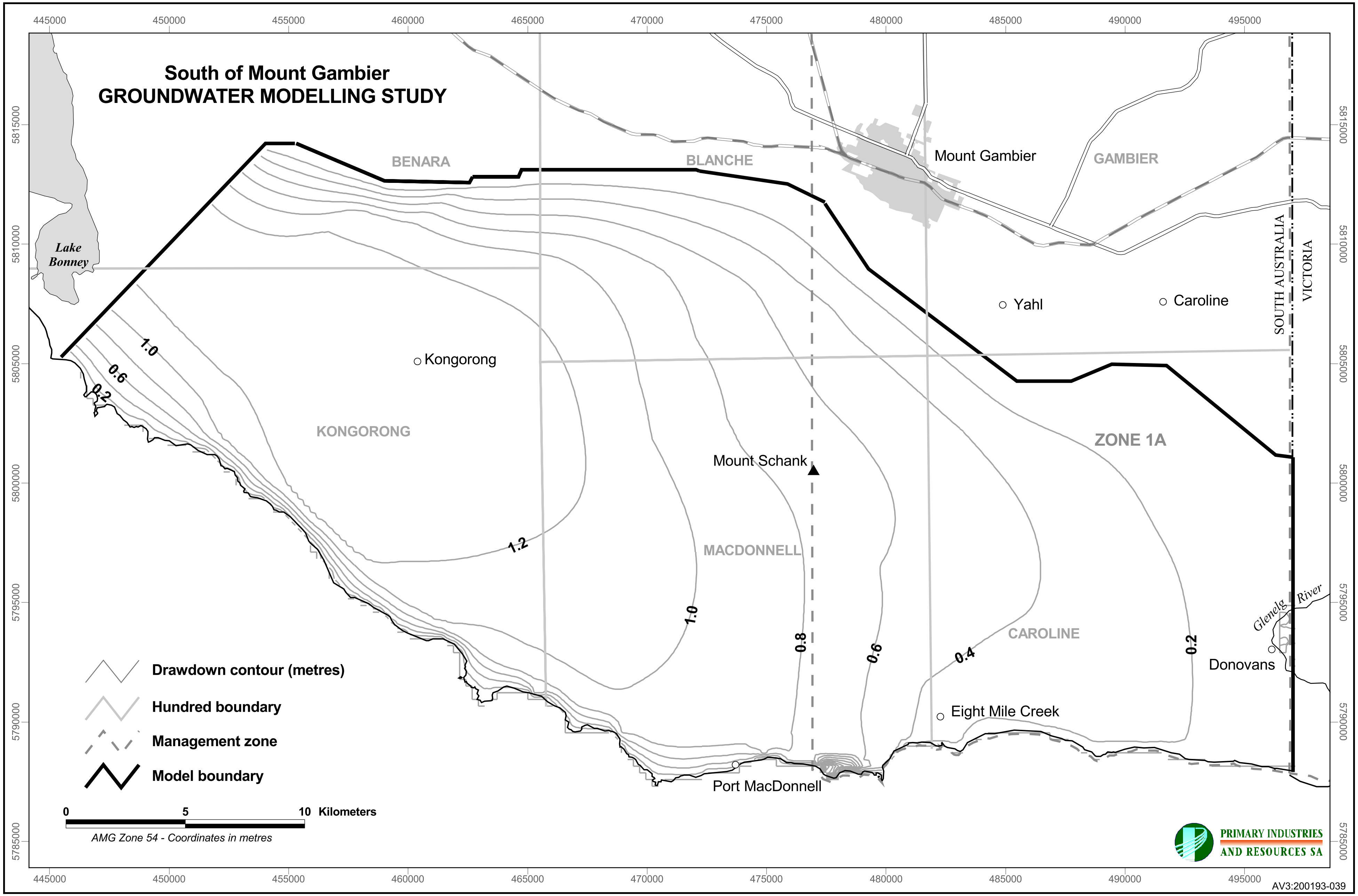
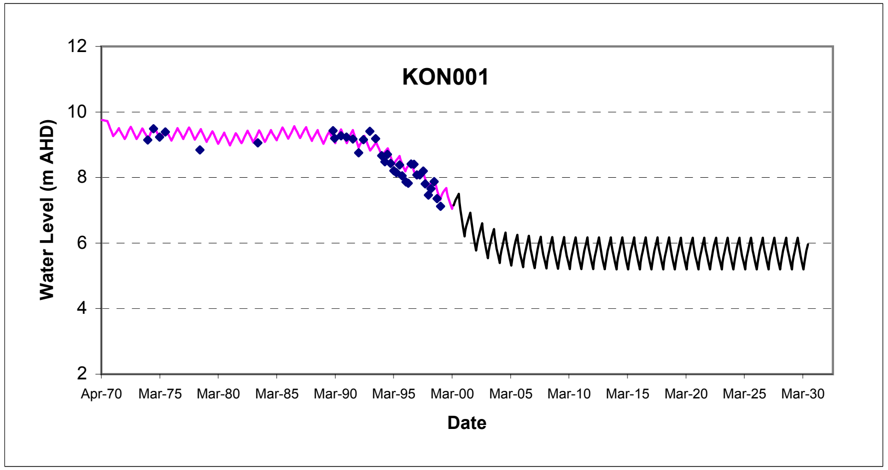
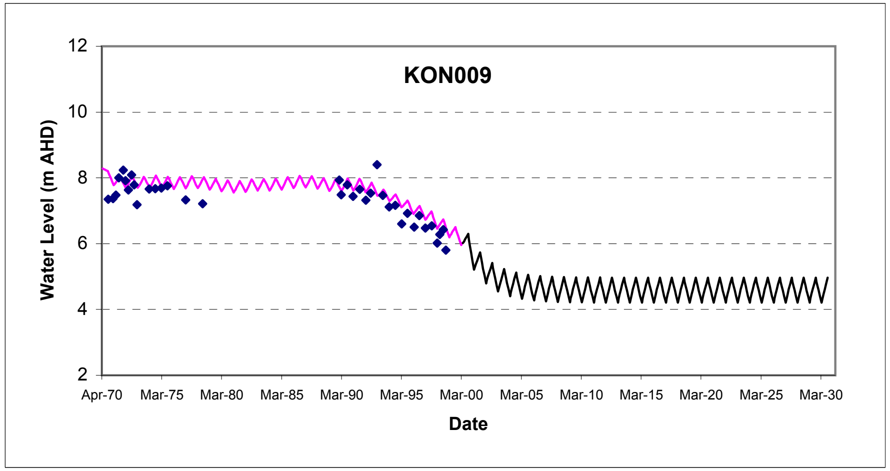
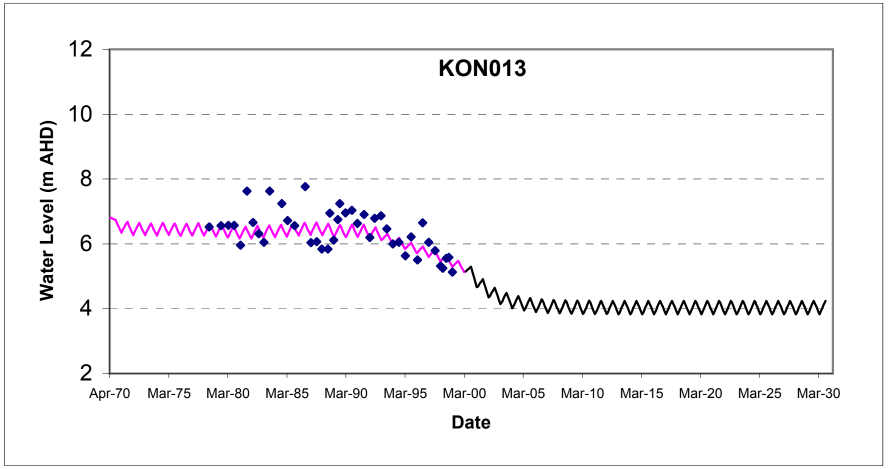
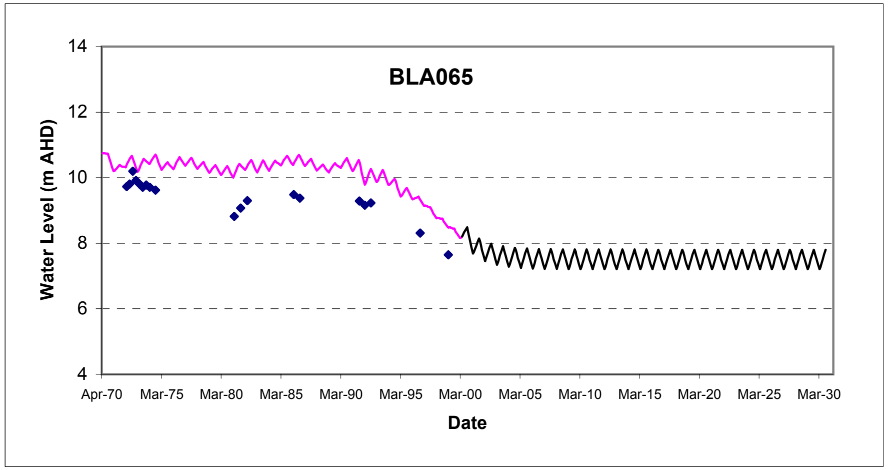


Figure E1-2 *Predicted residual drawdown contours for scenario 5 (2000 to 2030) with no head decline on the northern boundary.*

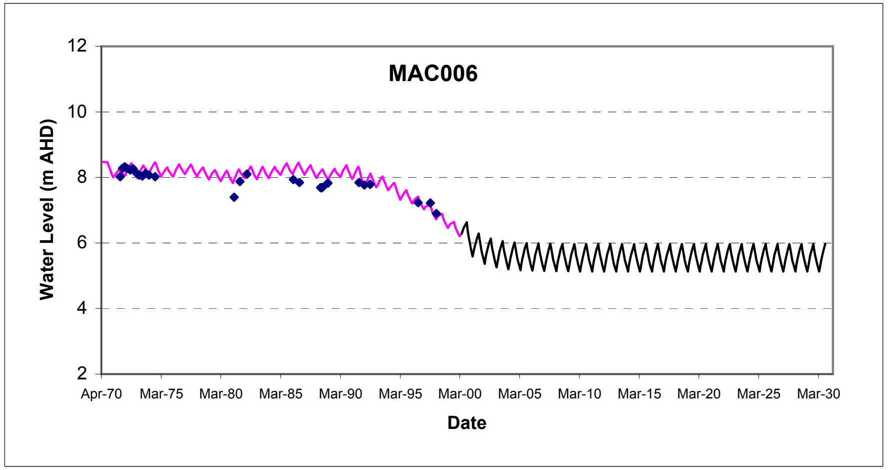


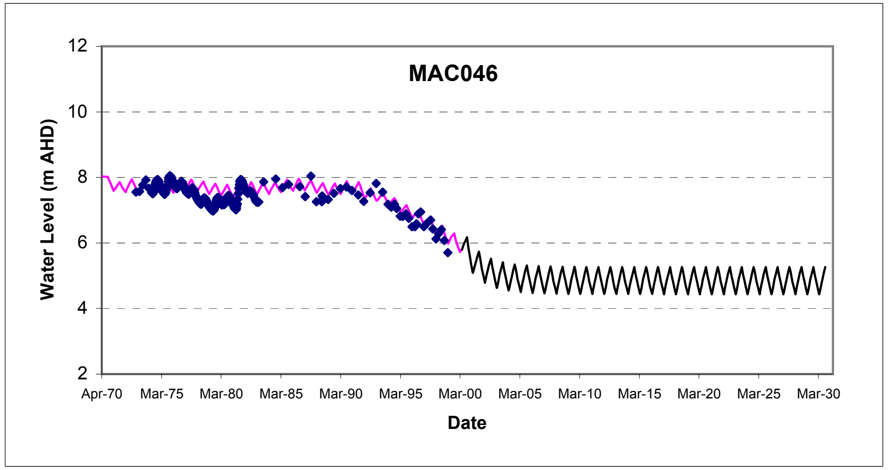


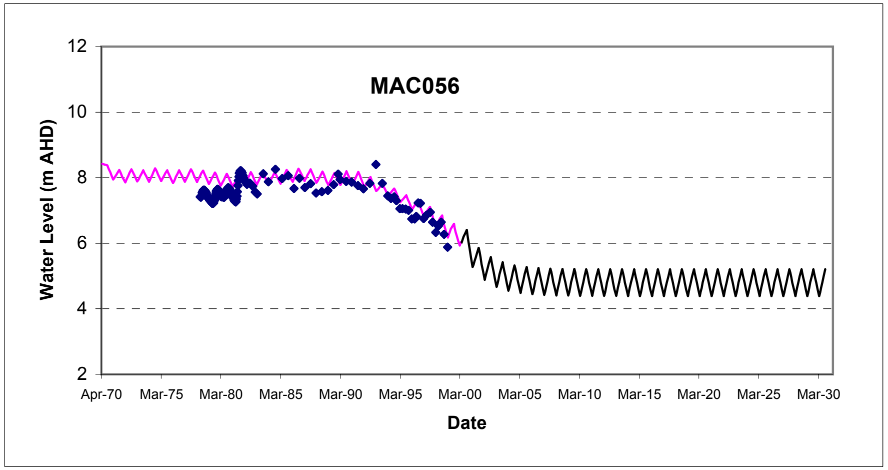


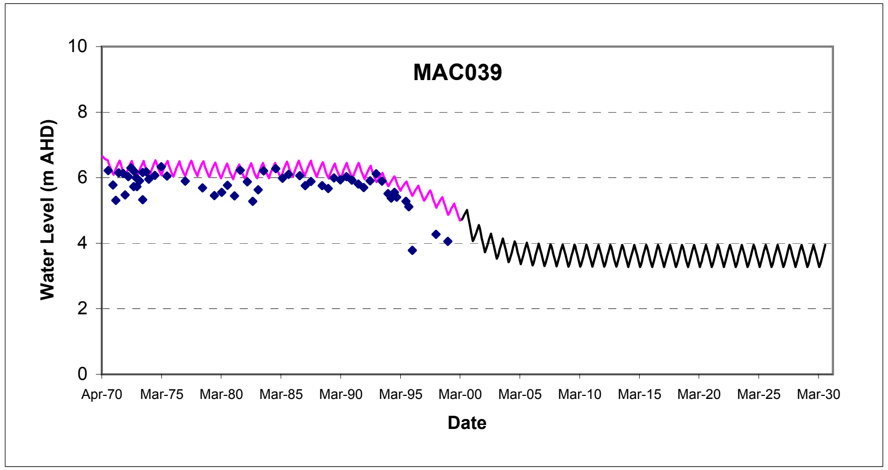


Appendix E1-3 *Hydrographs for Scenario 5 with no head decline on the northern boundary (1970-2030)*

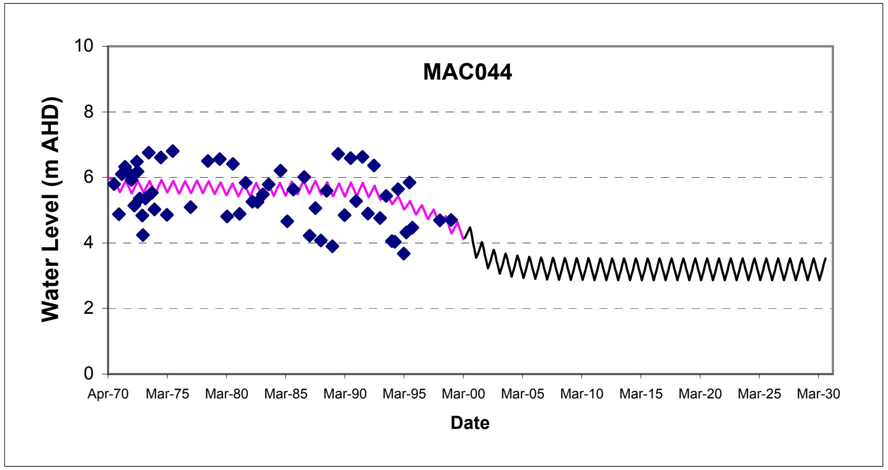


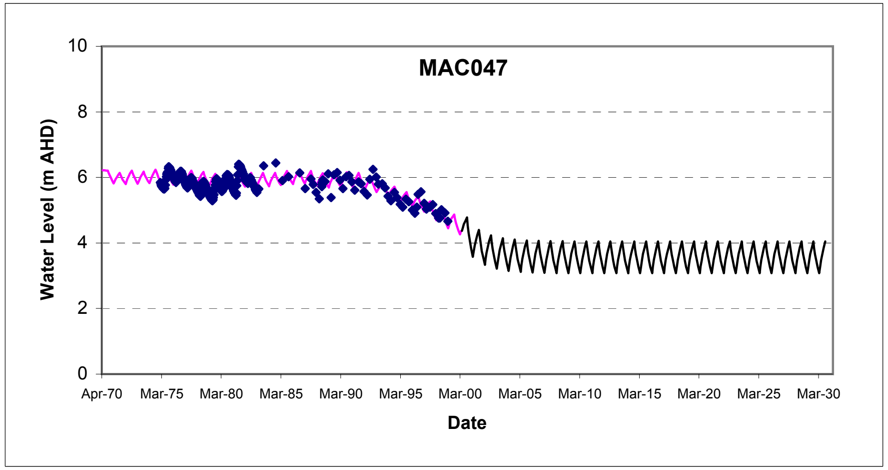


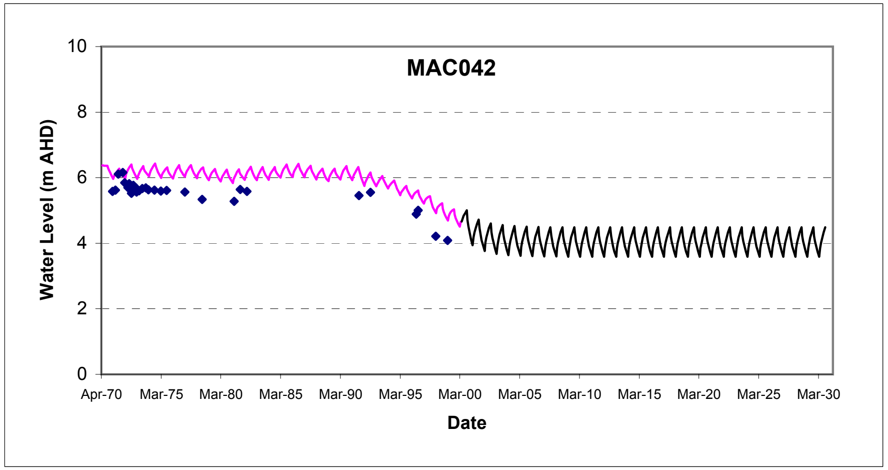


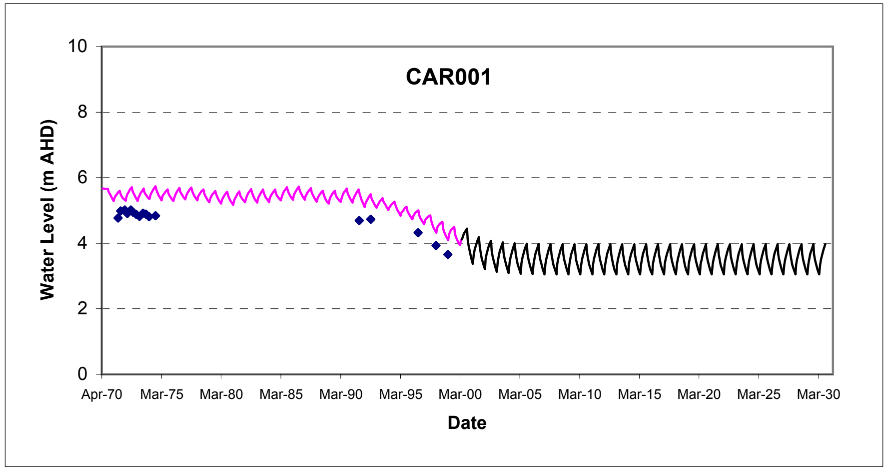


Appendix E1-4 *Hydrographs for Scenario 5 with no head decline on the northern boundary (1970-2030)*

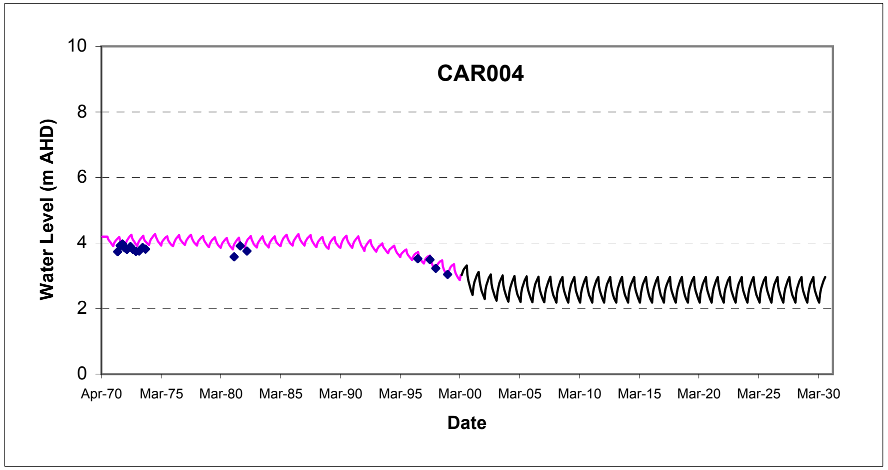


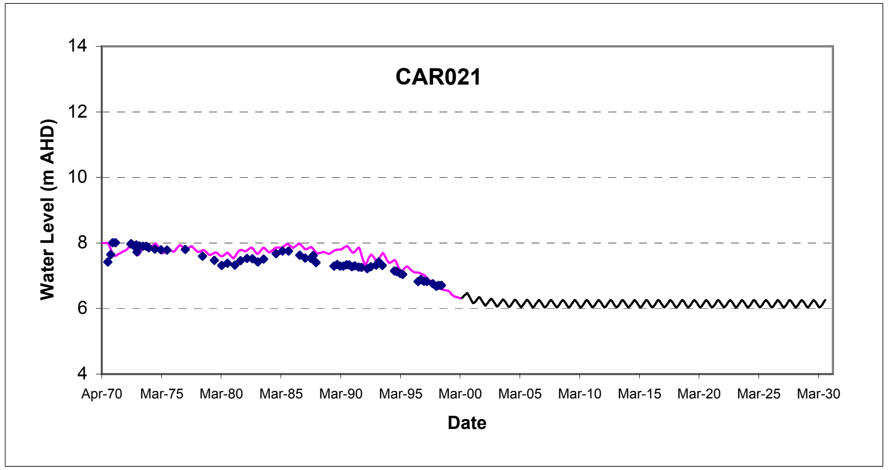


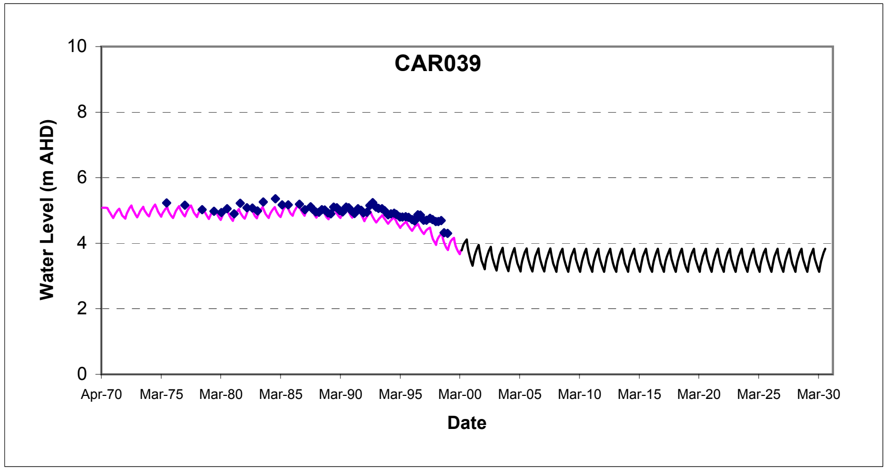


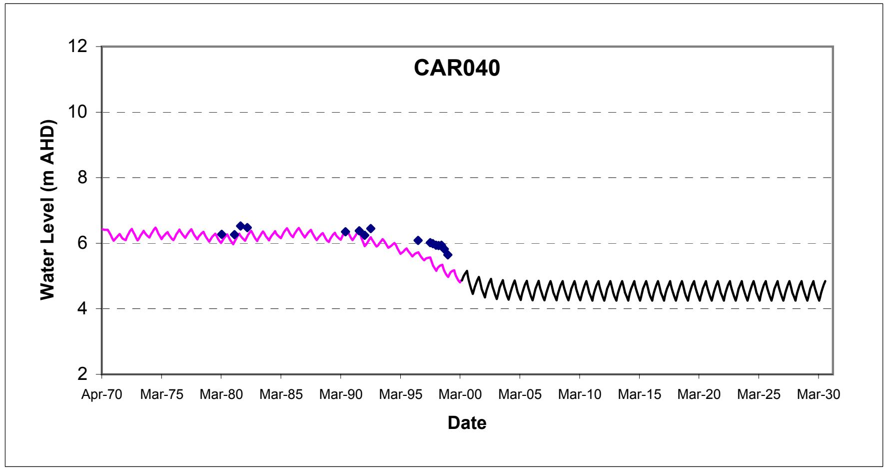


Appendix E1-5 *Hydrographs for Scenario 5 with no head decline on the northern boundary (1970-2030)*









Appendix E1-6 *Hydrographs for Scenario 5 with no head decline on the northern boundary (1970-2030)*

Appendix E2

Scenario 5: Results with a small head decline on the northern boundary

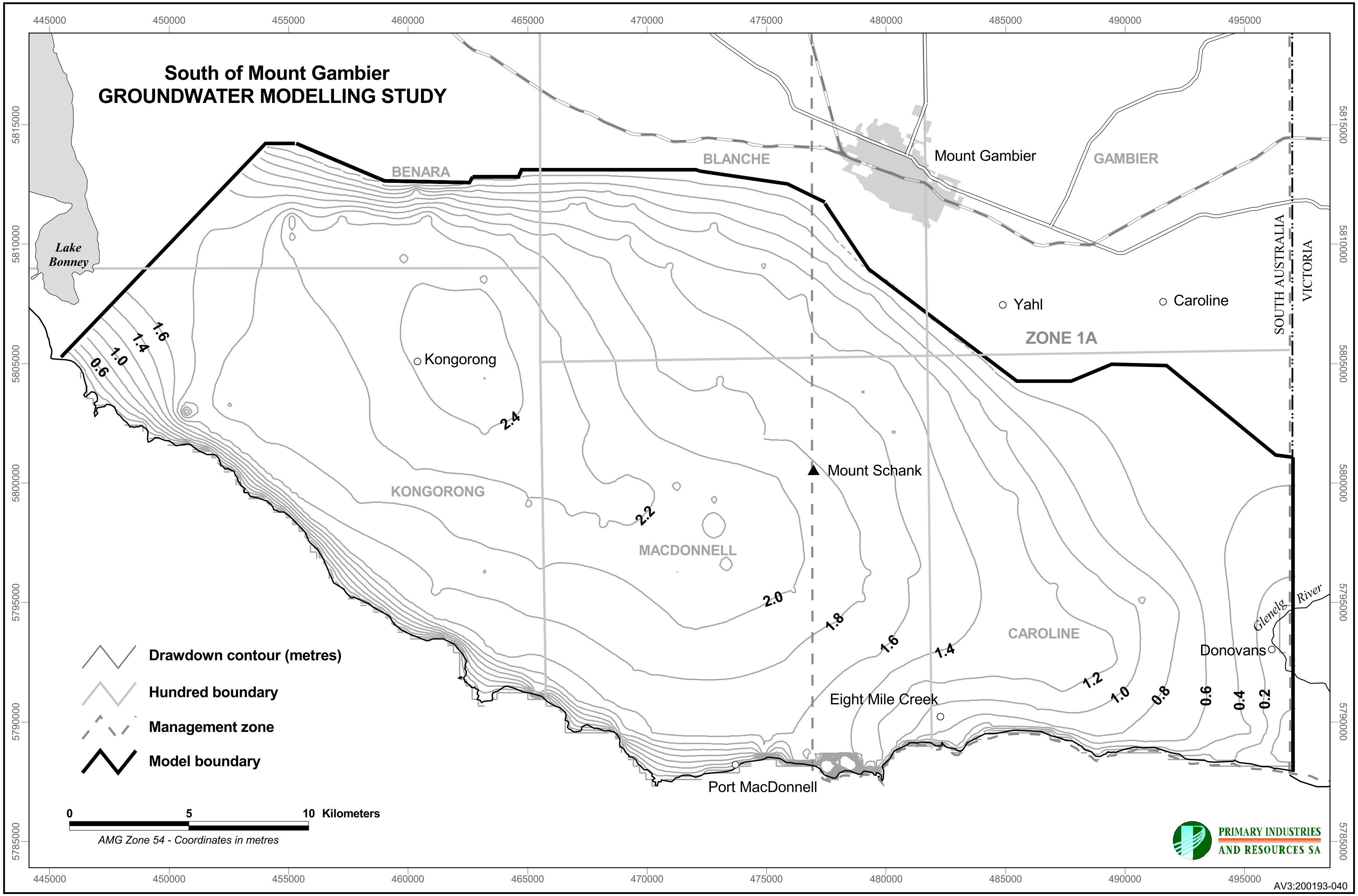


Figure E2-1 *Predicted maximum drawdown contours for scenario 5 (2000 to 2030) with small head decline on the northern boundary.*

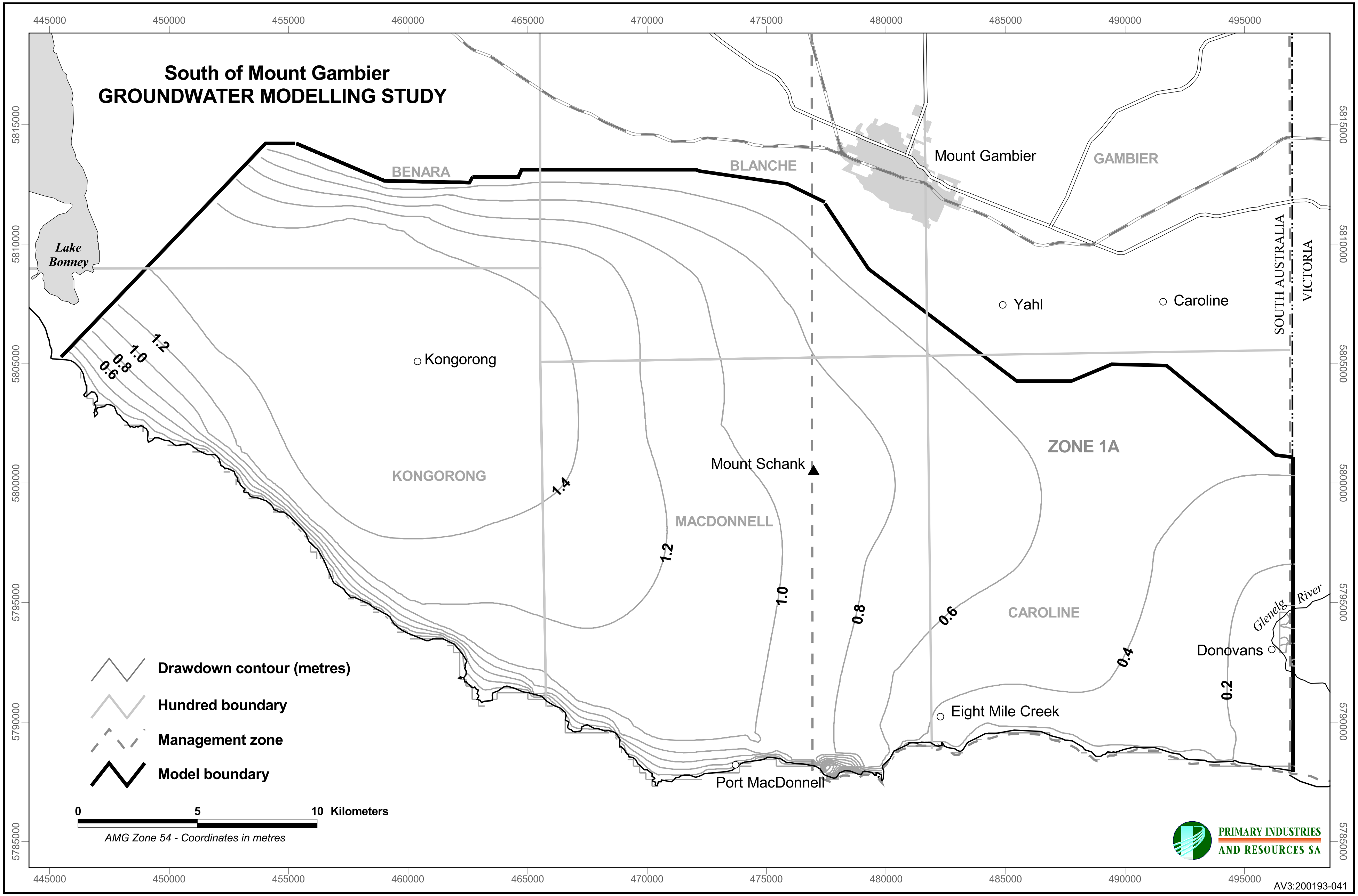
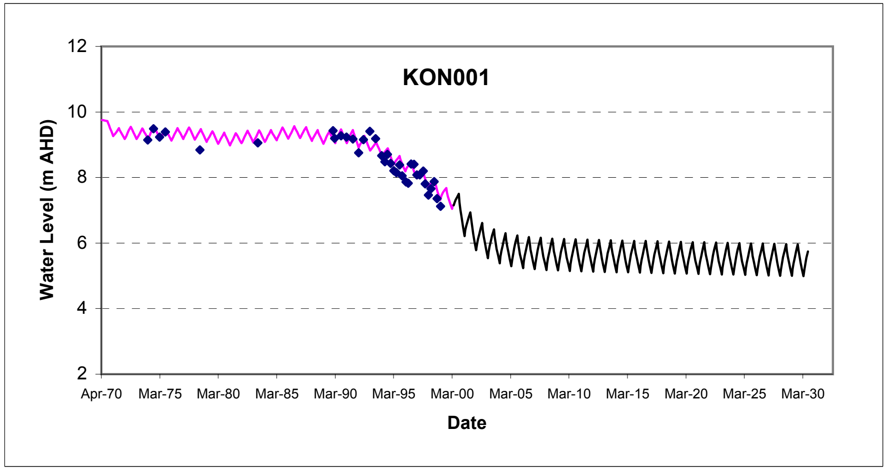
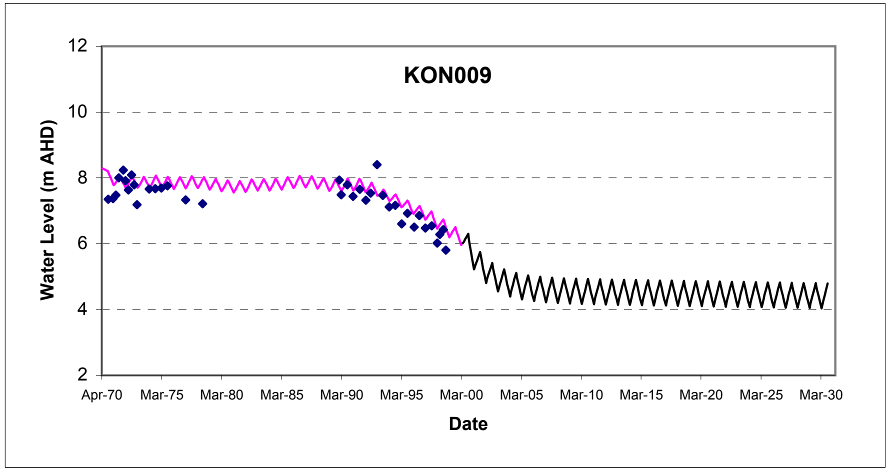
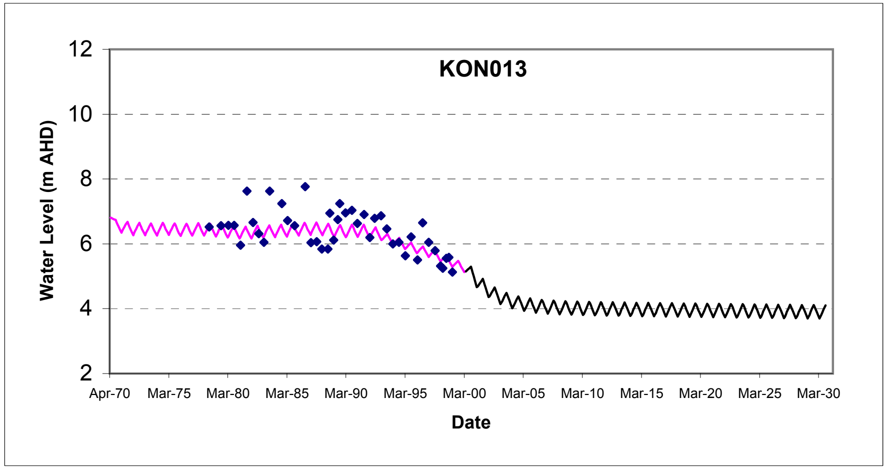
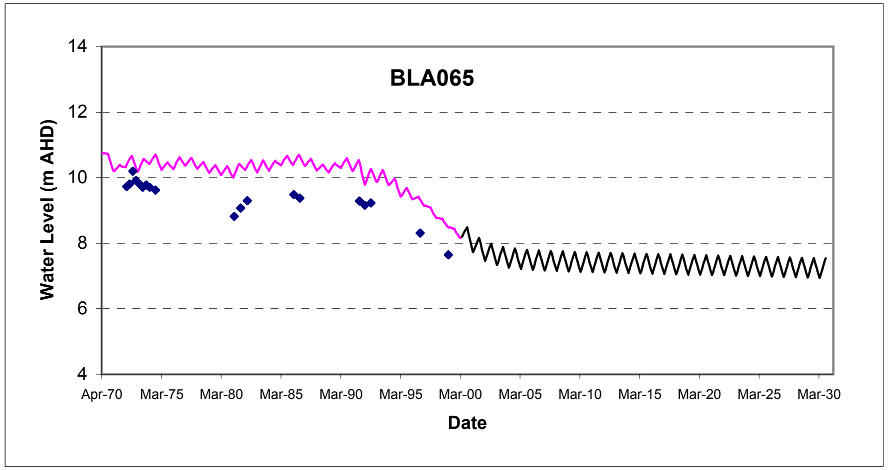


Figure E2-2 *Predicted residual drawdown contours for scenario 5 (2000 to 2030) with small head decline on the northern boundary.*

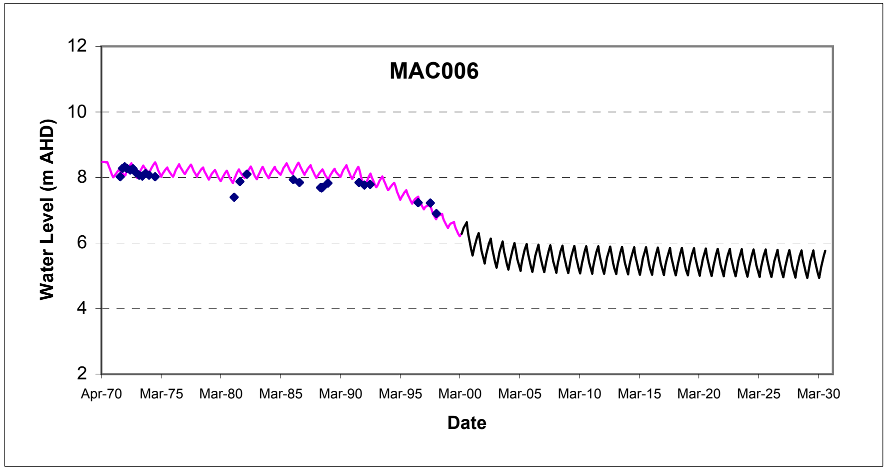


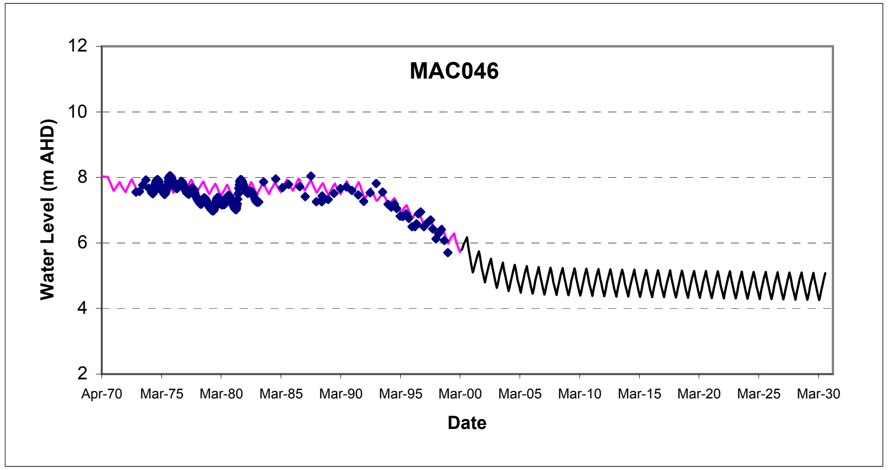


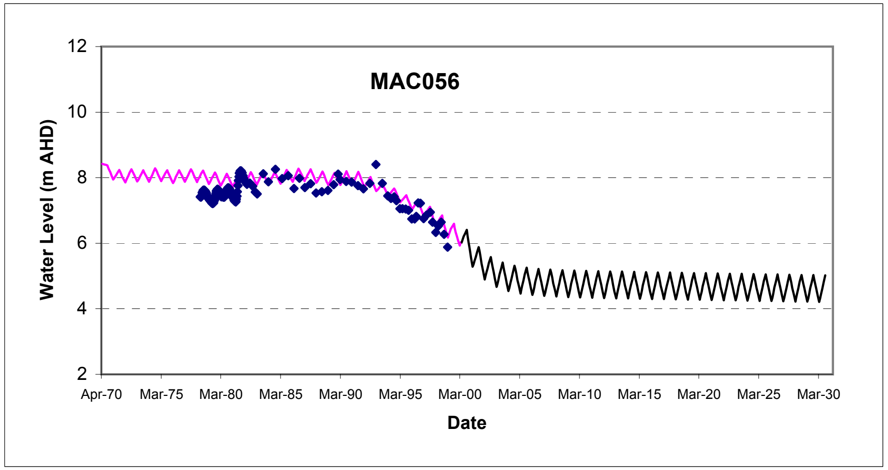


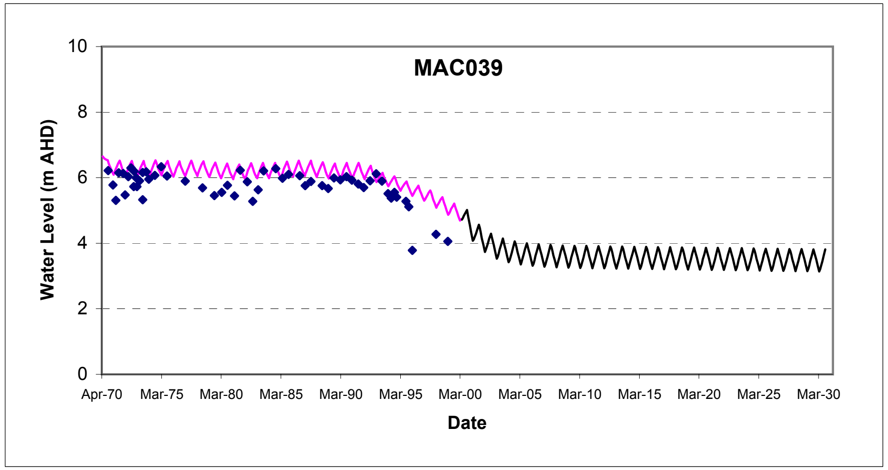


Appendix E2-3 *Hydrographs for Scenario 5 with small head decline on the northern boundary (1970-2030)*

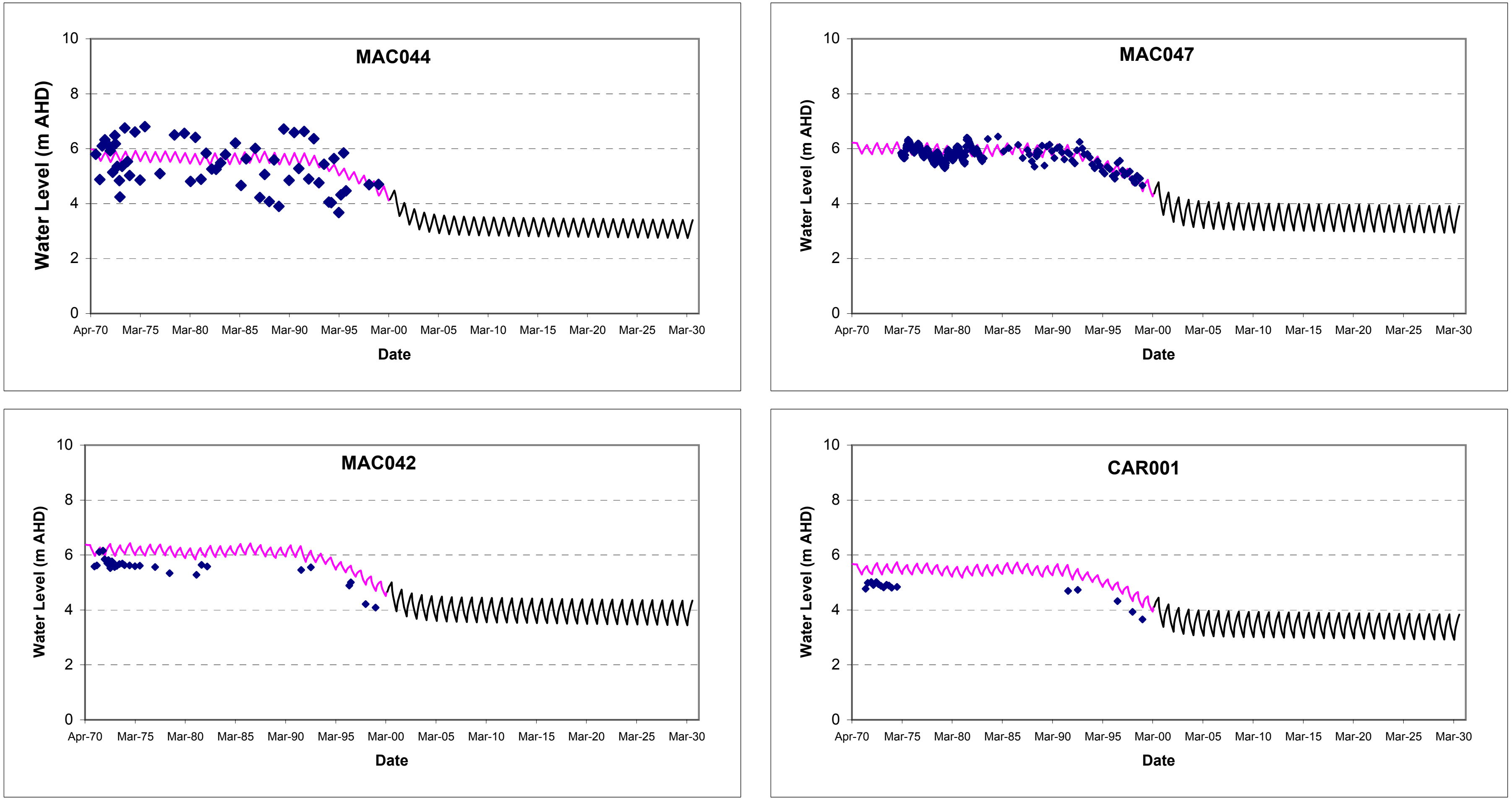




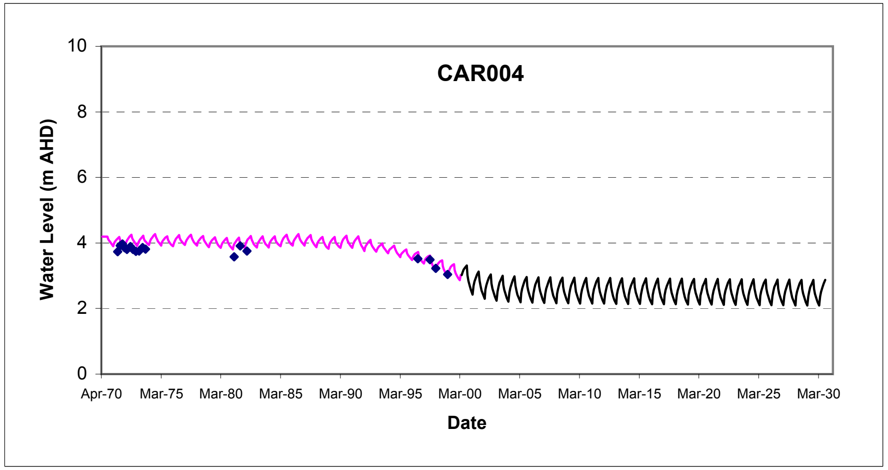


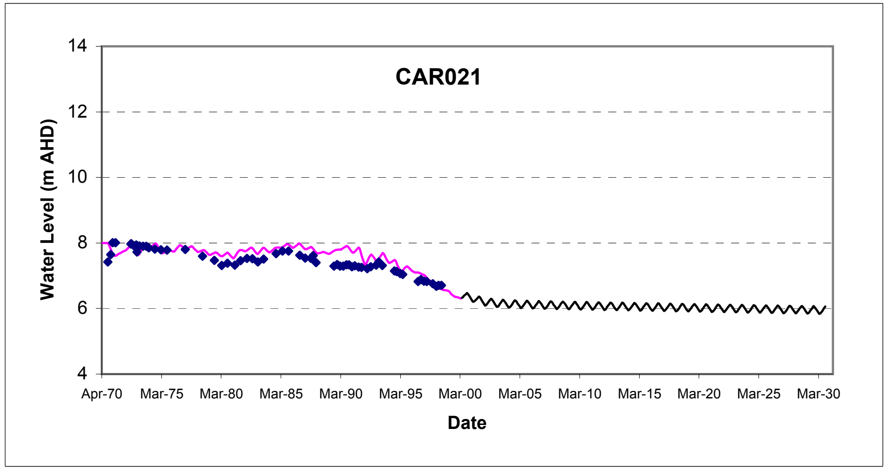


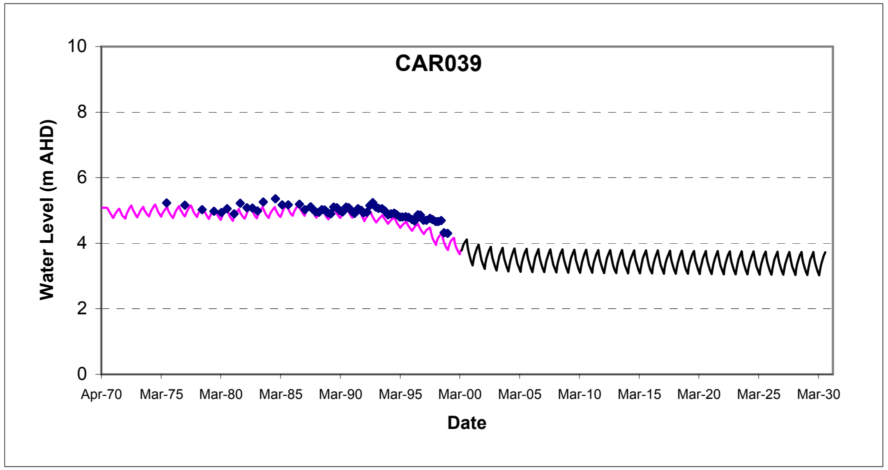
Appendix E2-4 *Hydrographs for Scenario 5 with small head decline on the northern boundary (1970-2030)*

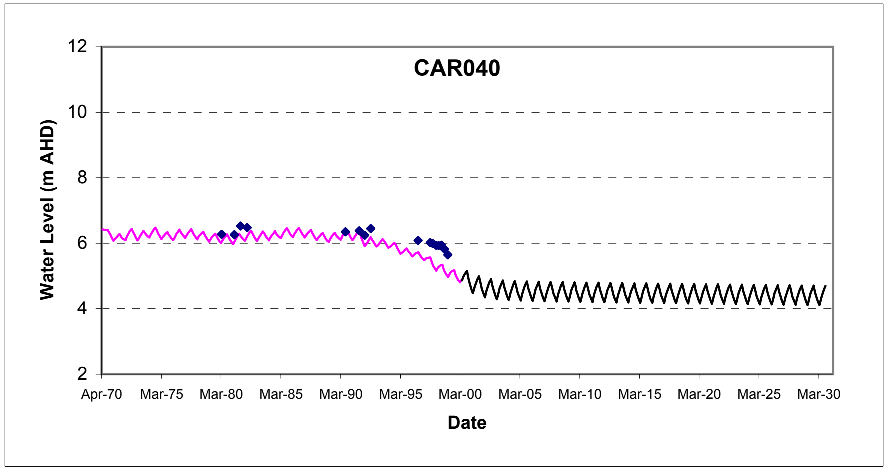


Appendix E2-5 *Hydrographs for Scenario 5 with small head decline on the northern boundary (1970-2030)*









Appendix E2-6 *Hydrographs for Scenario 5 with small head decline on the northern boundary (1970-2030)*

Appendix E3

Scenario 5: Results with a large head decline

on the northern boundary

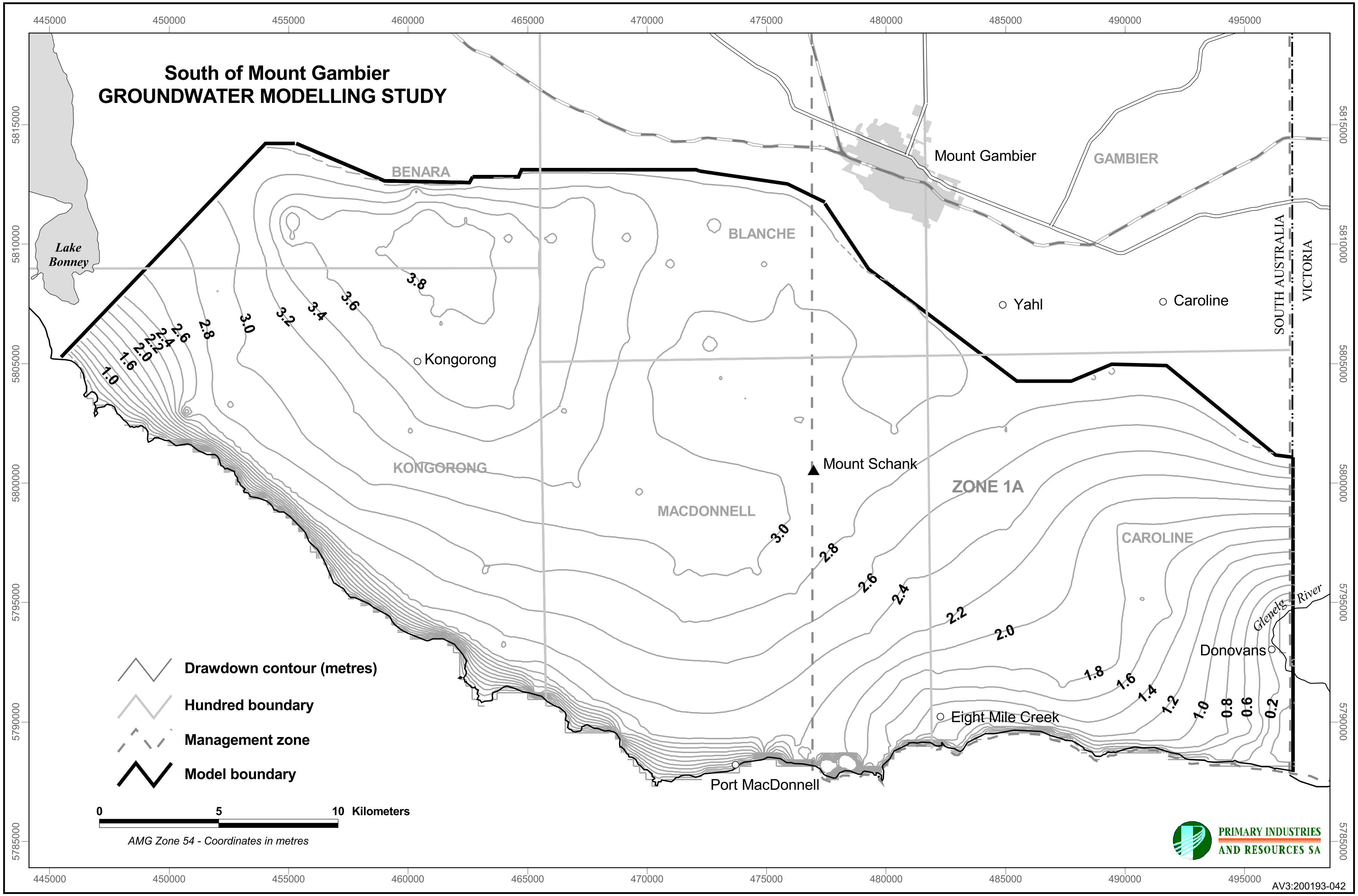


Figure E3-1 *Predicted maximum drawdown contours for scenario 5 (2000 to 2030) with large head decline on the northern boundary.*

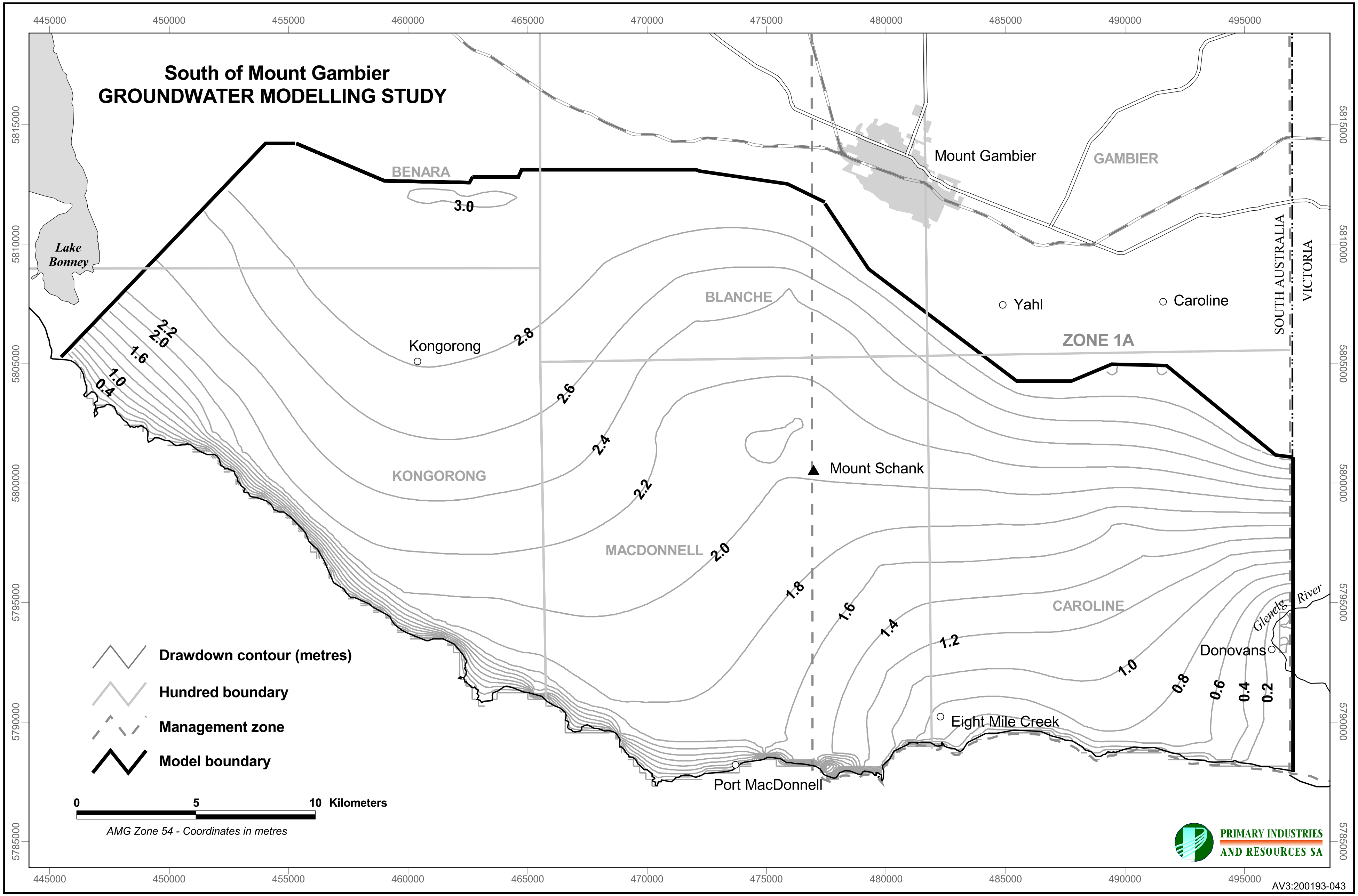
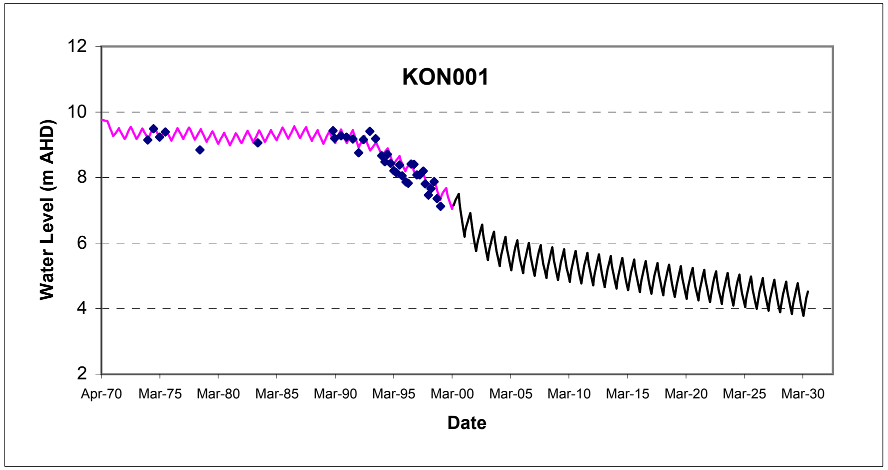
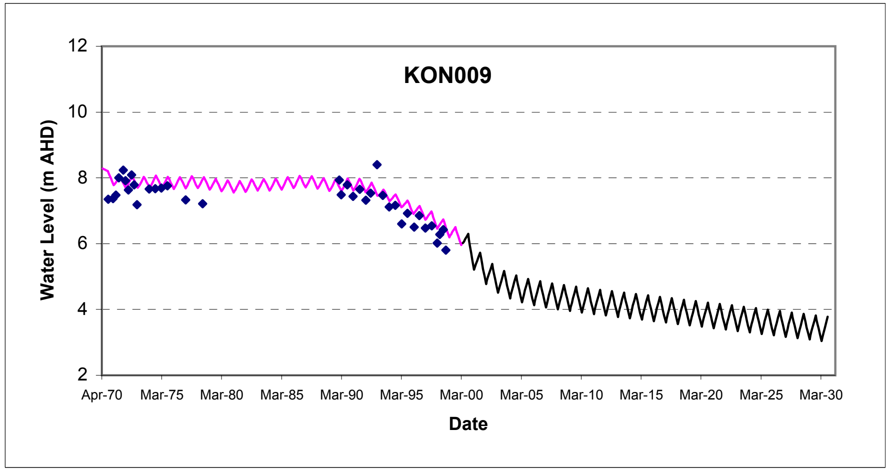
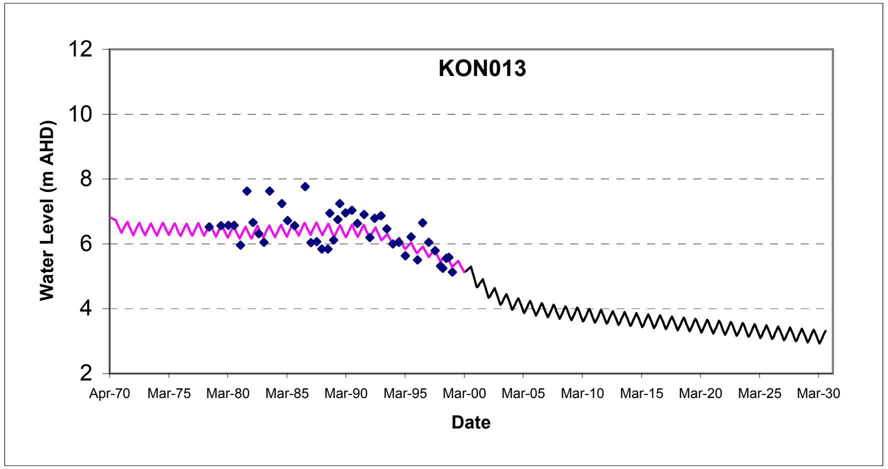
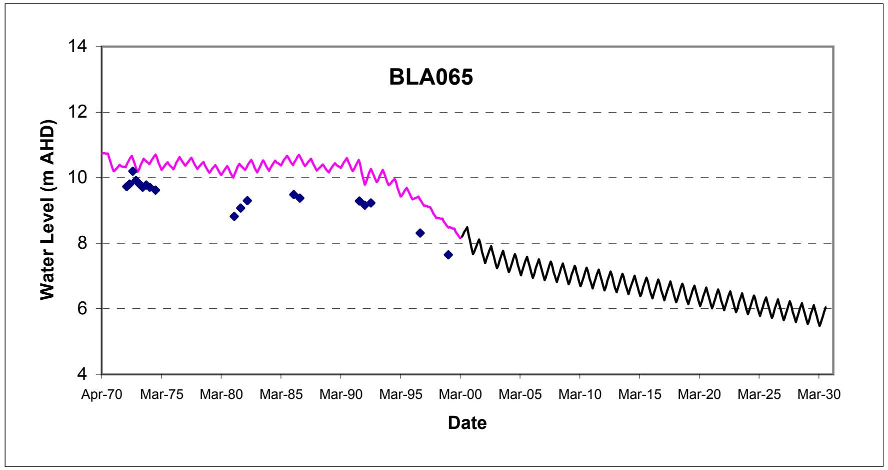


Figure E3-2 *Predicted residual drawdown contours for scenario 5 (2000 to 2030) with large head decline on the northern boundary.*

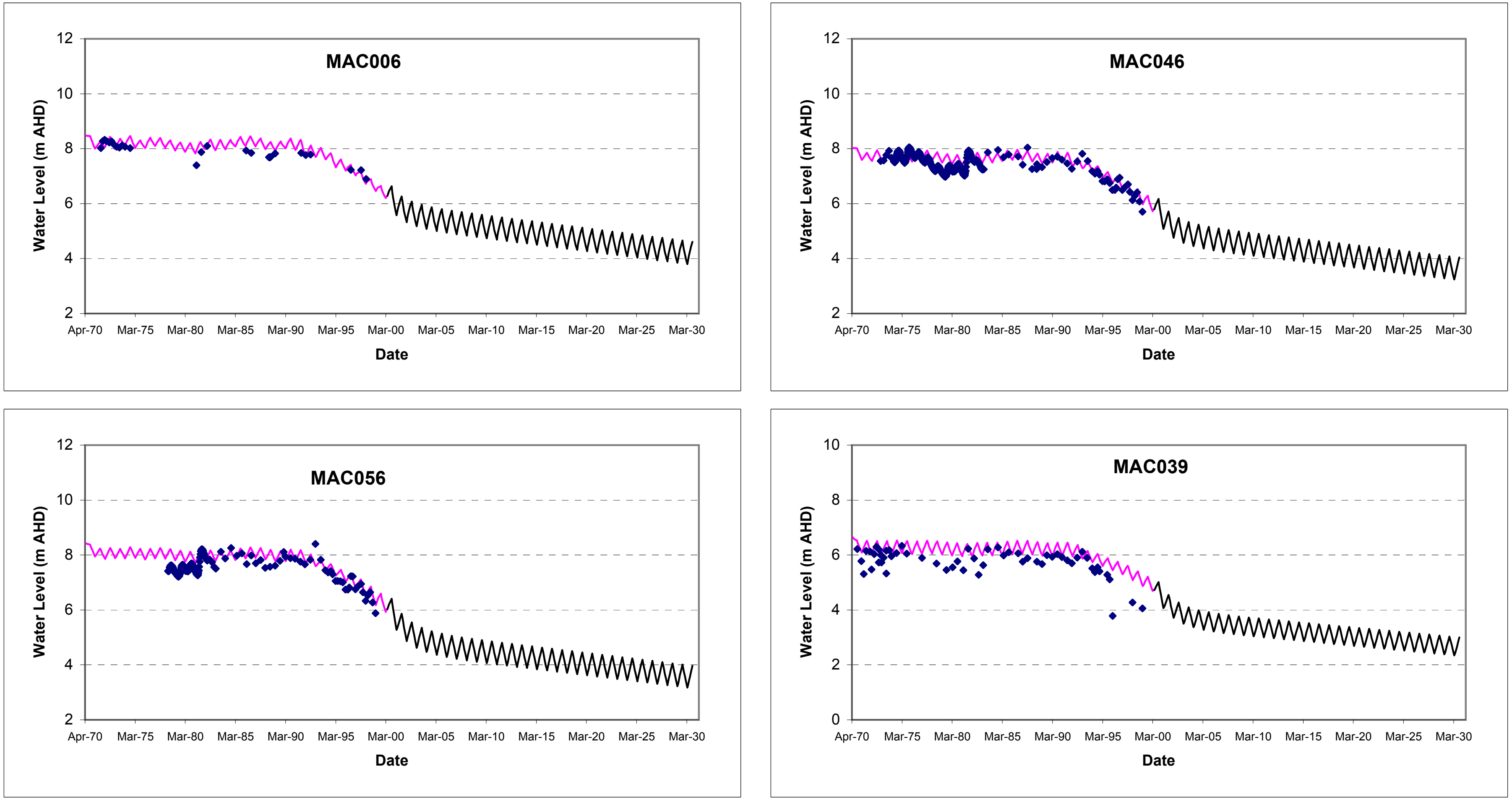




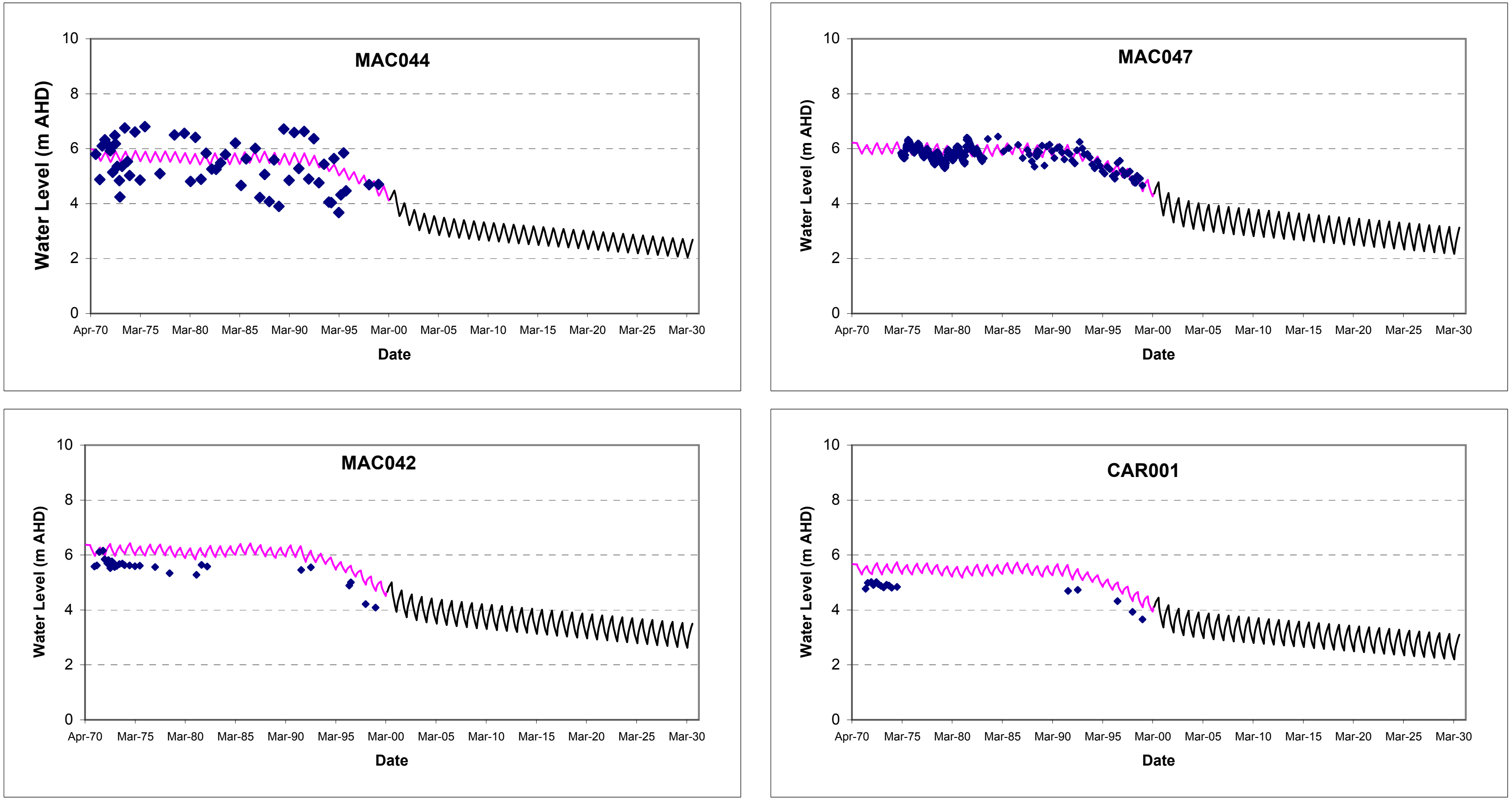




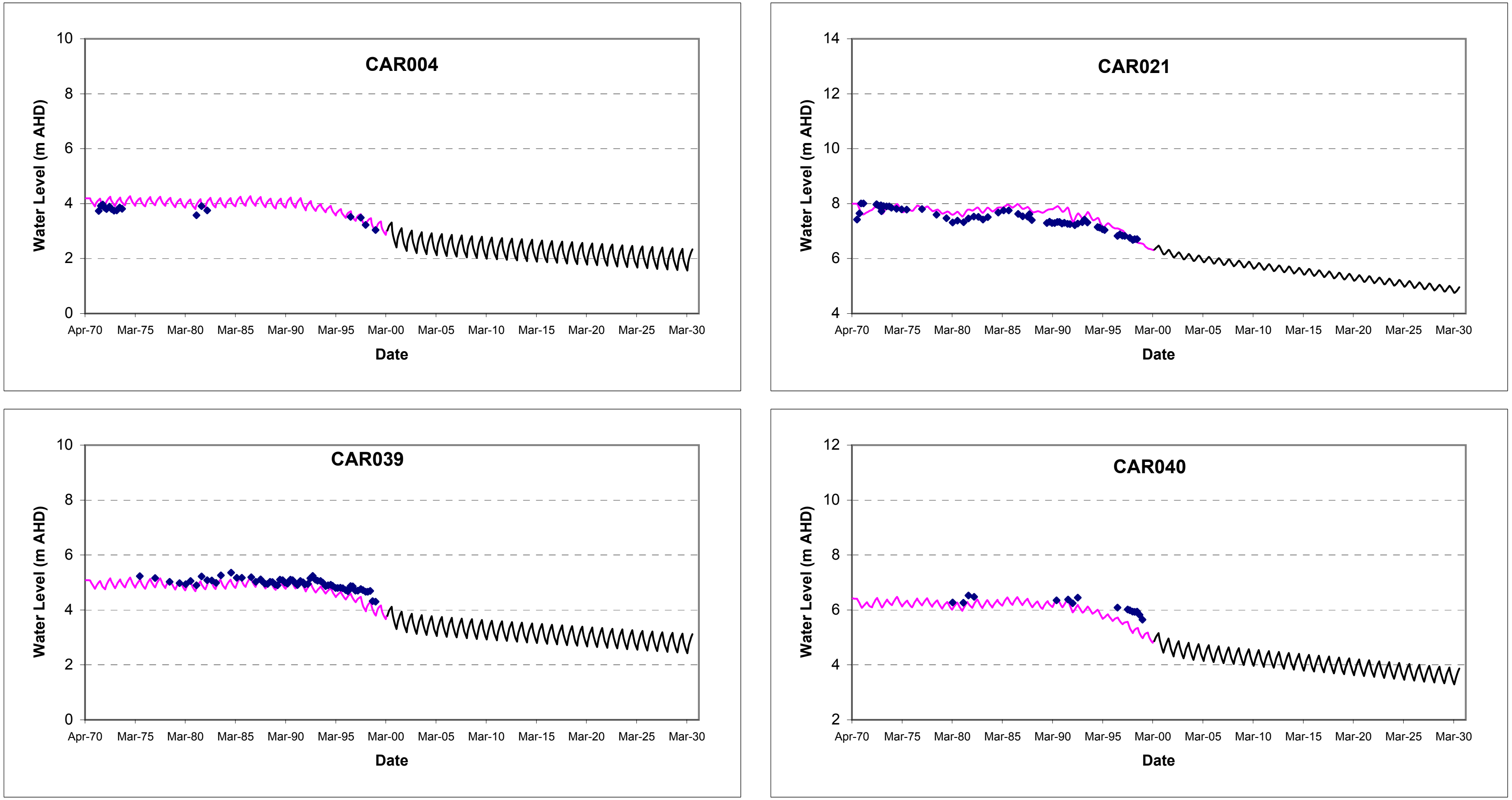
Appendix E3-3 *Hydrographs for Scenario 5 with large head decline on the northern boundary (1970-2030)*



Appendix E3-4 *Hydrographs for Scenario 5 with large head decline on the northern boundary (1970-2030)*



Appendix E3-5 *Hydrographs for Scenario 5 with large head decline on the northern boundary (1970-2030)*



Appendix E3-6 *Hydrographs for Scenario 5 with large head decline on the northern boundary (1970-2030)*

Appendix F1

Scenario 6: Results with a no head decline

on the northern boundary

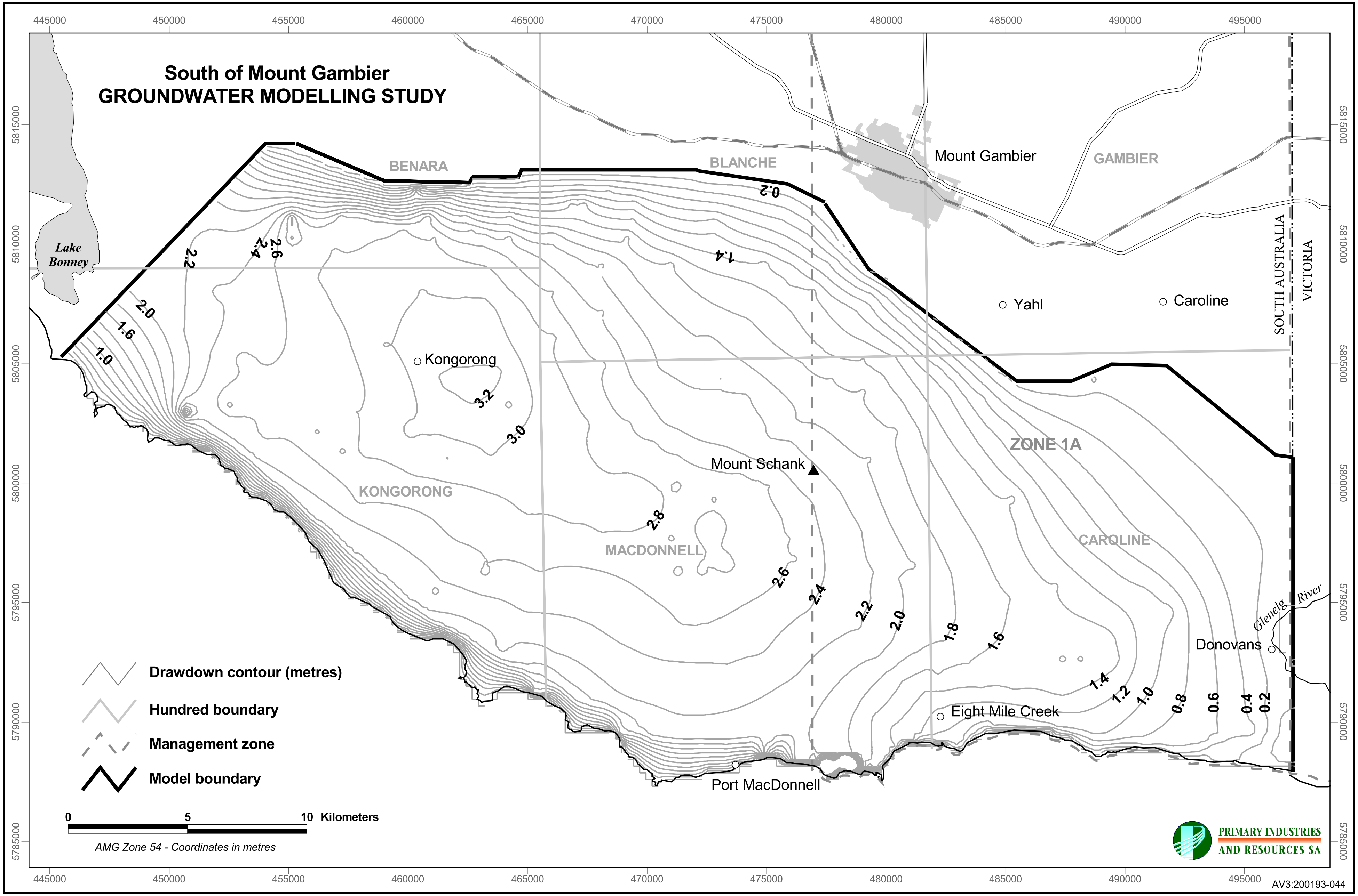


Figure F1-1 *Predicted maximum drawdown contours for scenario 6 (2000 to 2030) with no head decline on the northern boundary.*

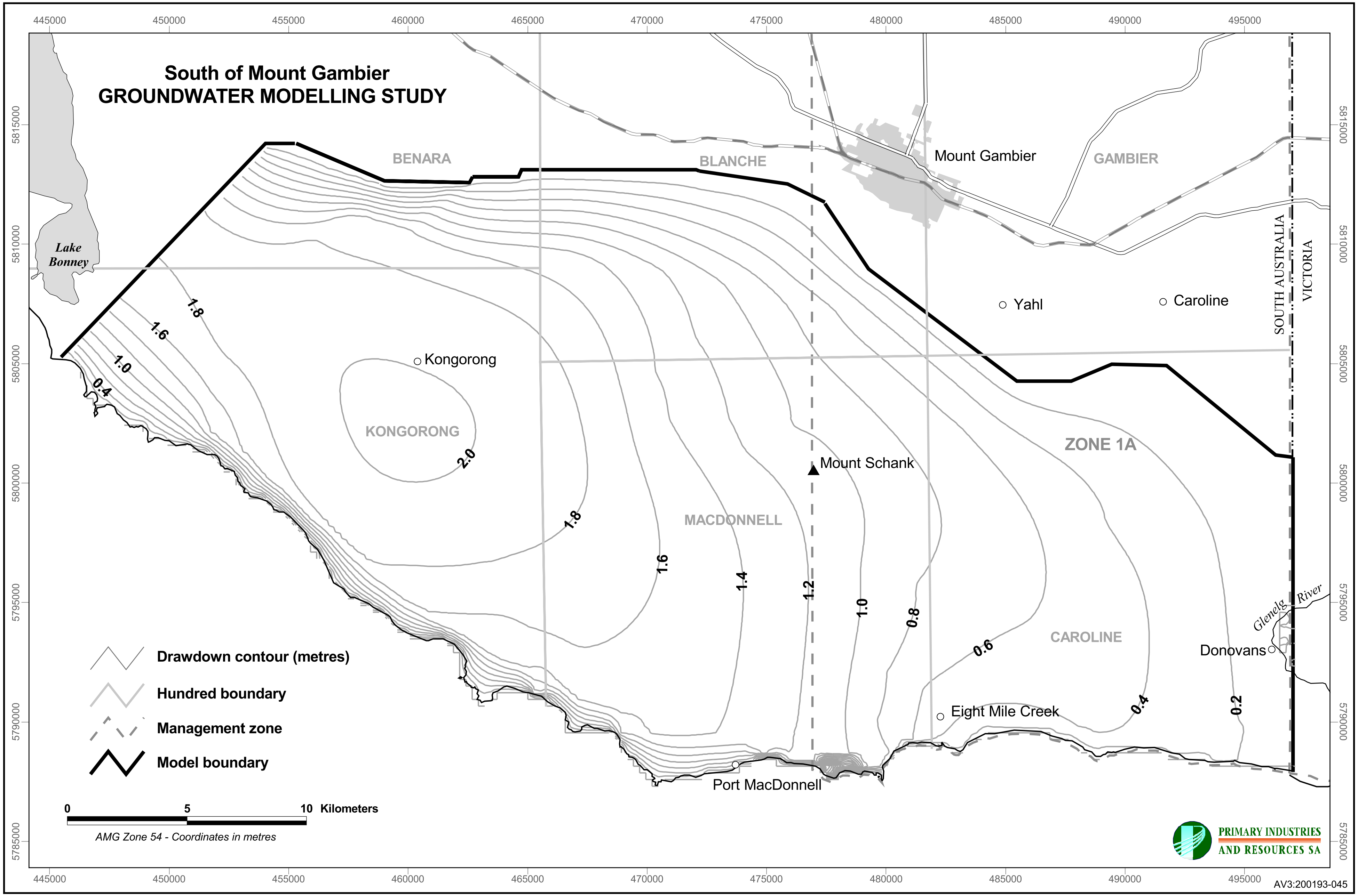
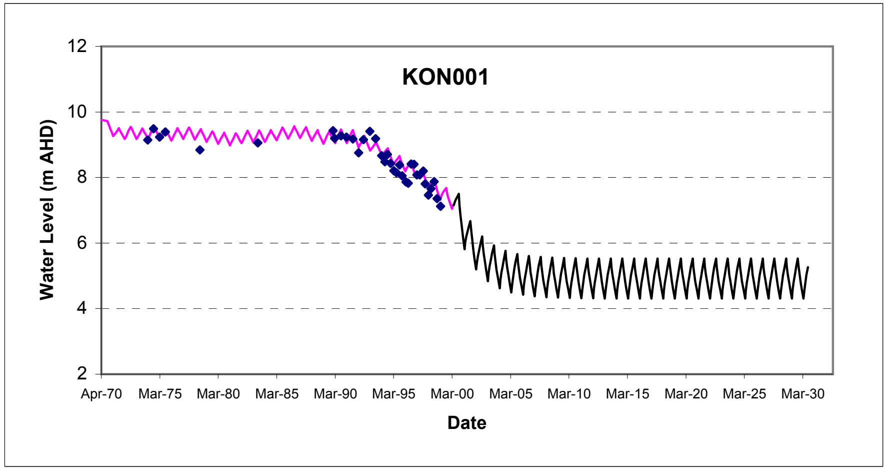
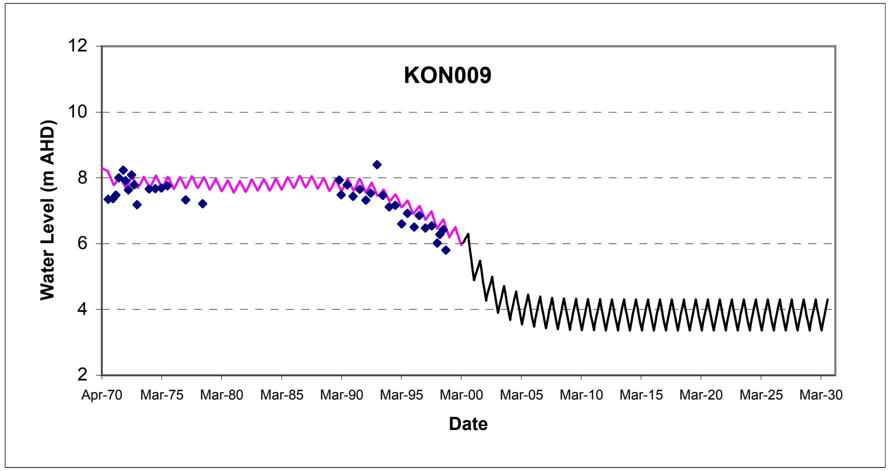
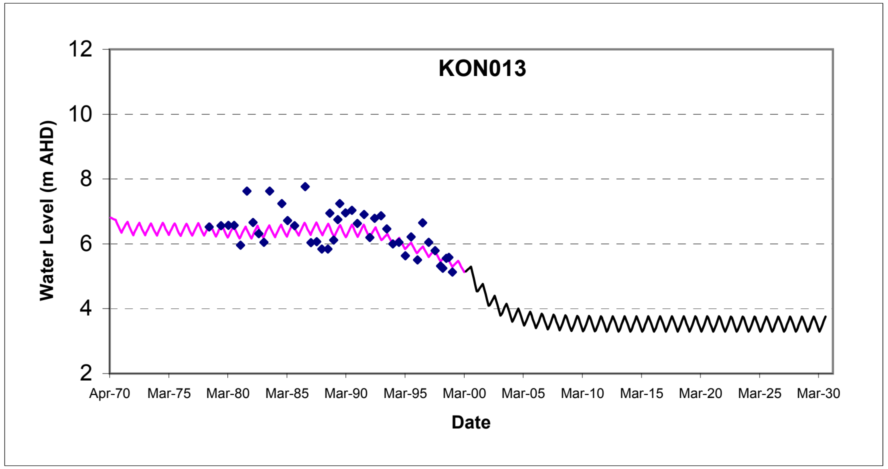
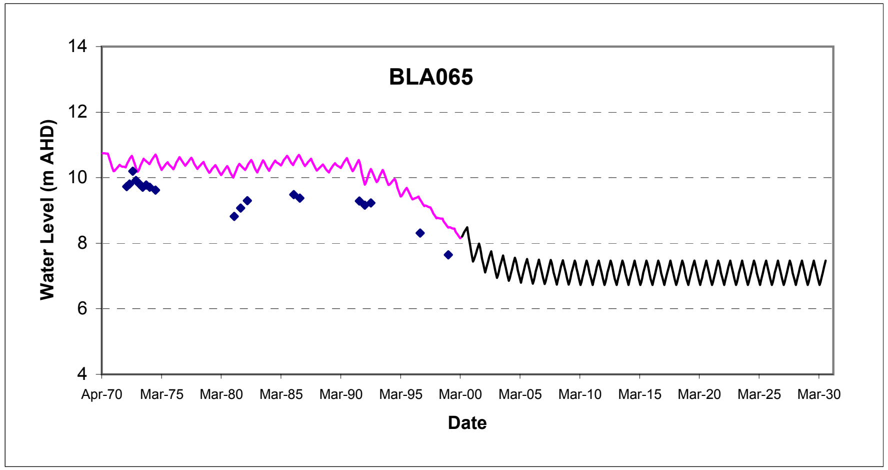


Figure F1-2 *Predicted residual drawdown contours for scenario 6 (2000 to 2030) with no head decline on the northern boundary.*

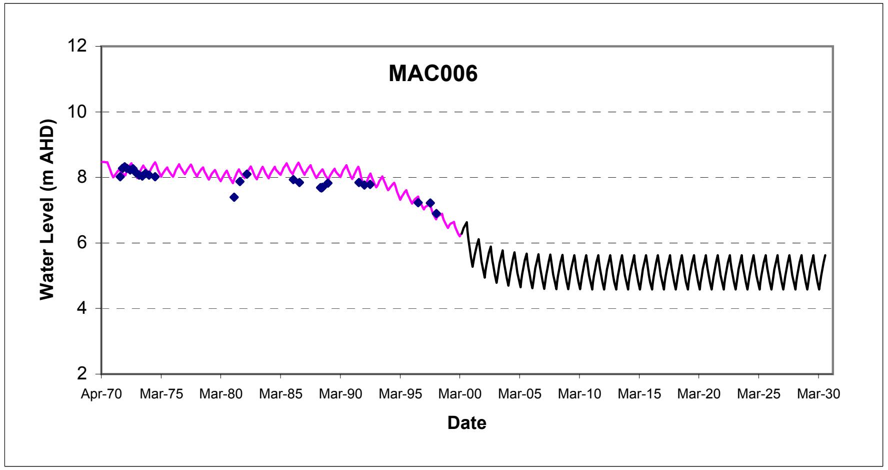


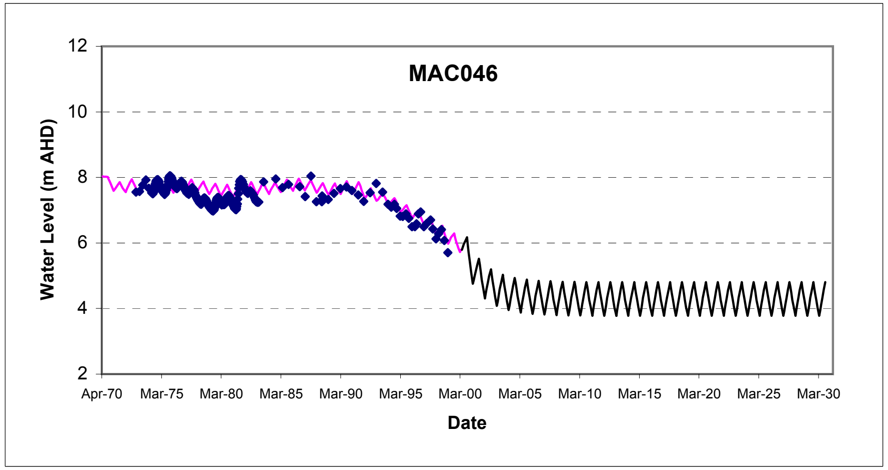


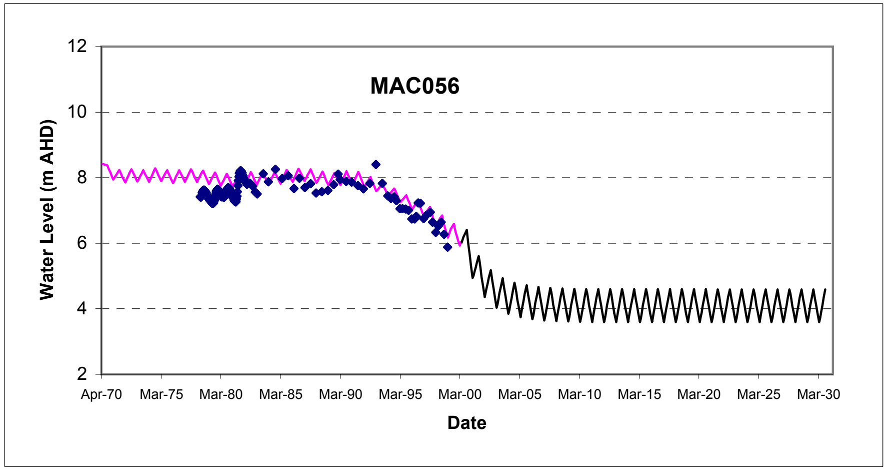


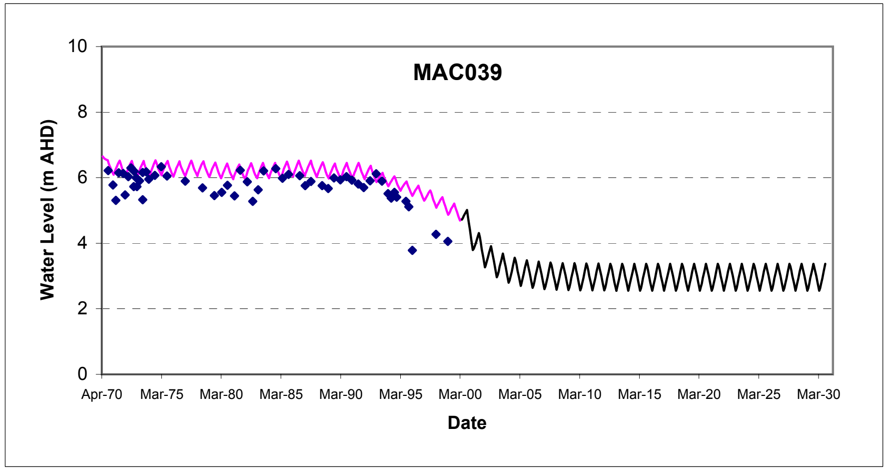


Appendix F1-3 *Hydrographs for Scenario 6 with no head decline on the northern boundary (1970-2030)*

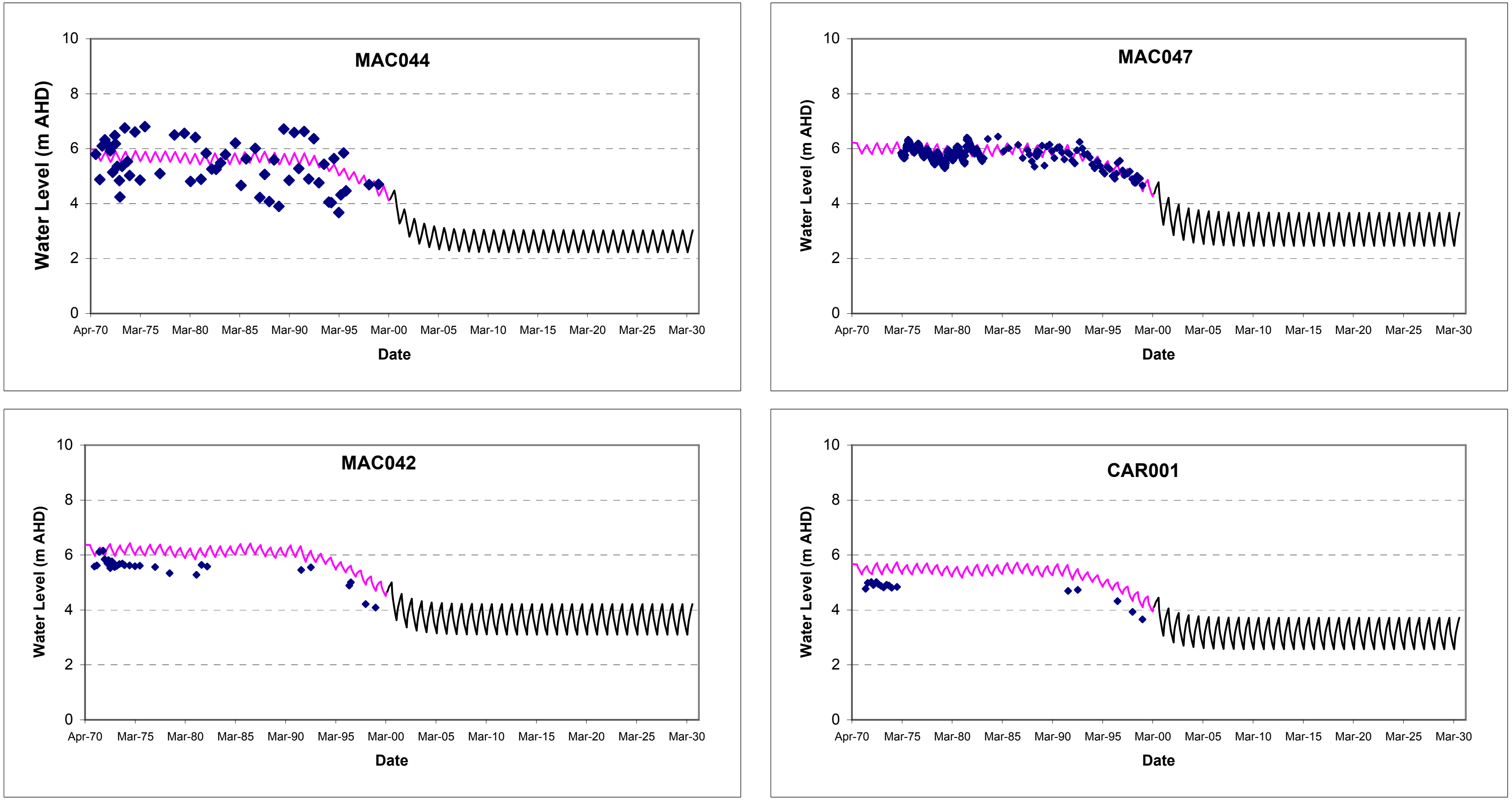




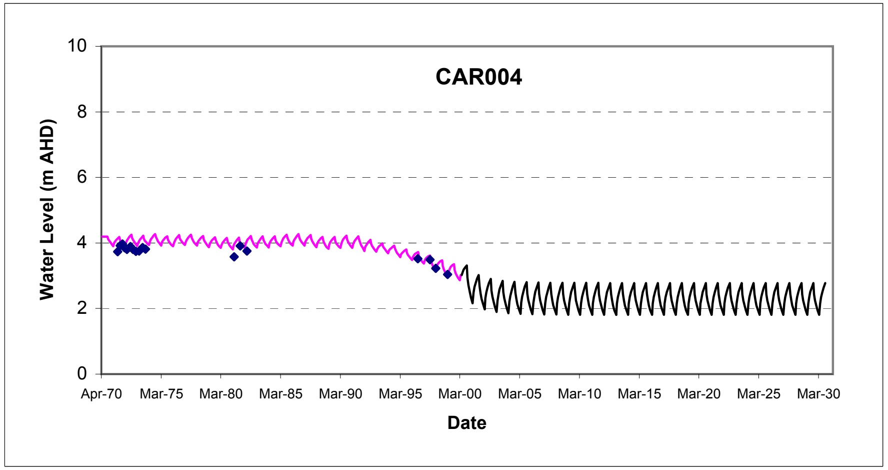


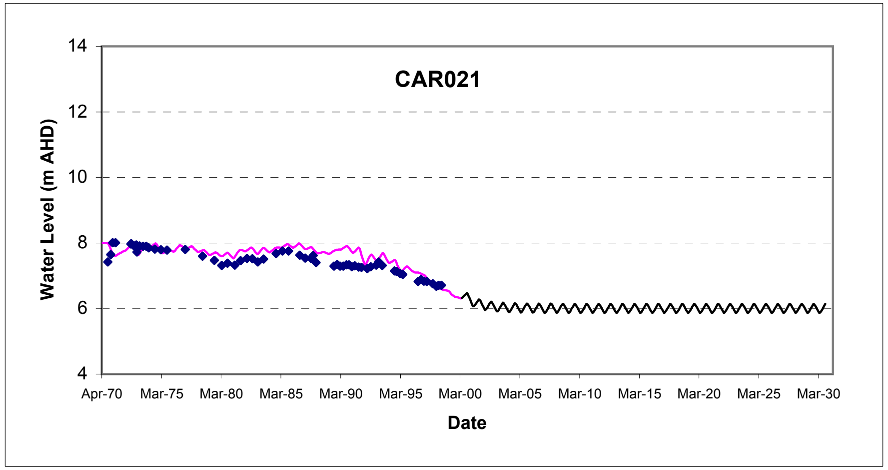


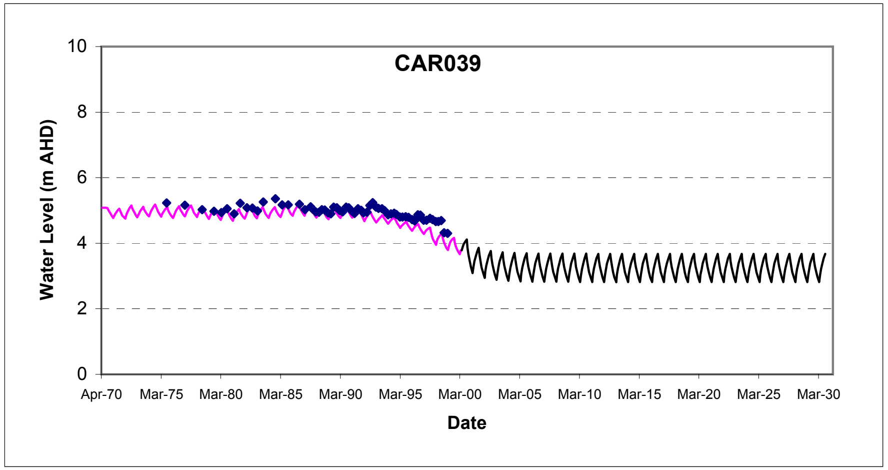
Appendix F1-4 *Hydrographs for Scenario 6 with no head decline on the northern boundary (1970-2030)*

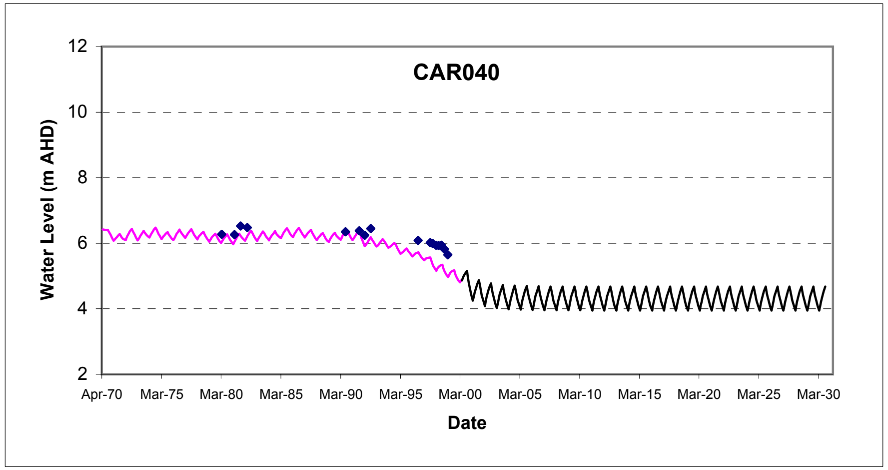


Appendix F1-5 *Hydrographs for Scenario 6 with no head decline on the northern boundary (1970-2030)*









Appendix F1-6 *Hydrographs for Scenario 6 with no head decline on the northern boundary (1970-2030)*

Appendix F2

Scenario 6: Results with a small head decline on the northern boundary

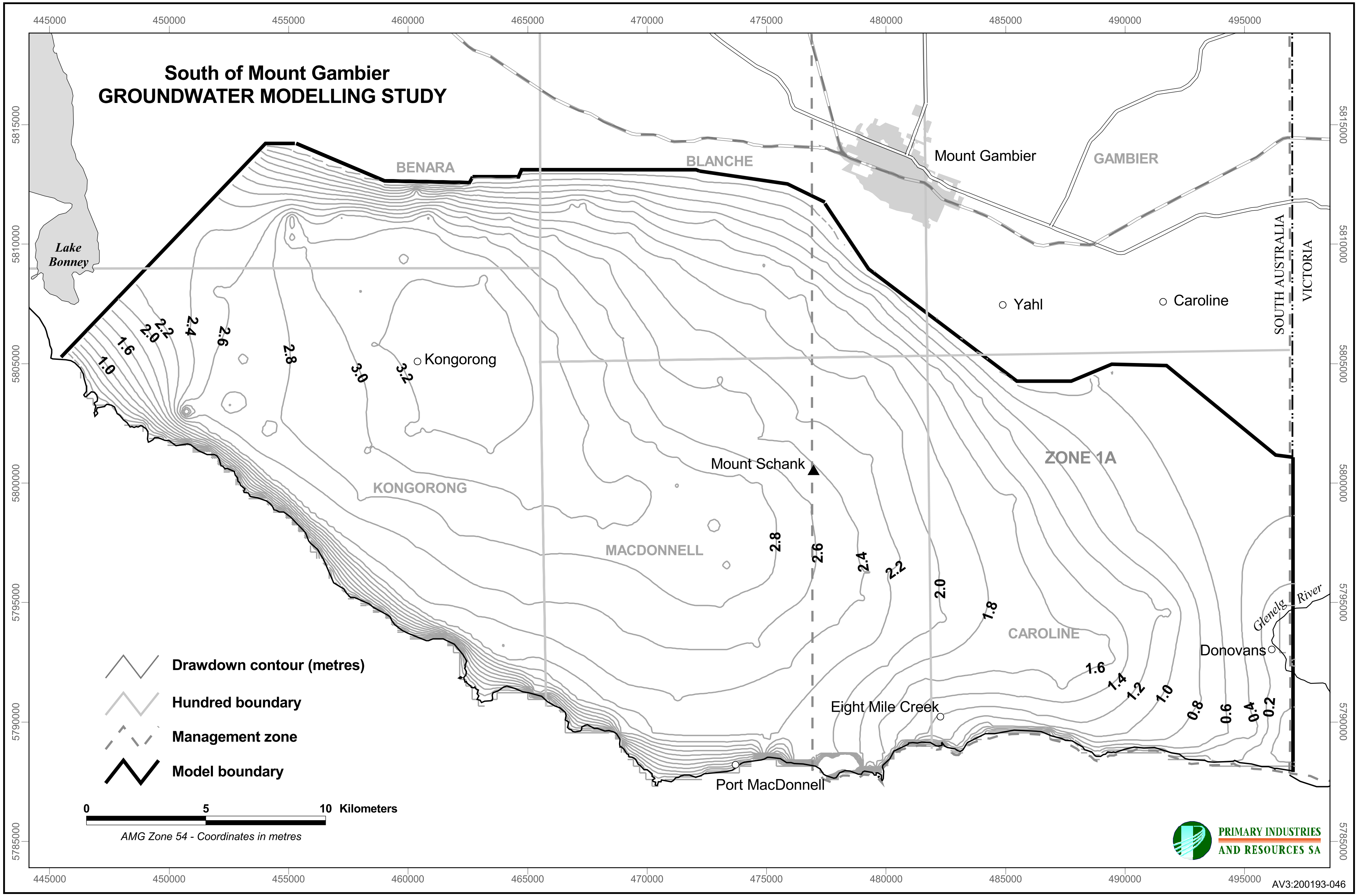


Figure F2-1 *Predicted maximum drawdown contours for scenario 6 (2000 to 2030) with small head decline on the northern boundary.*

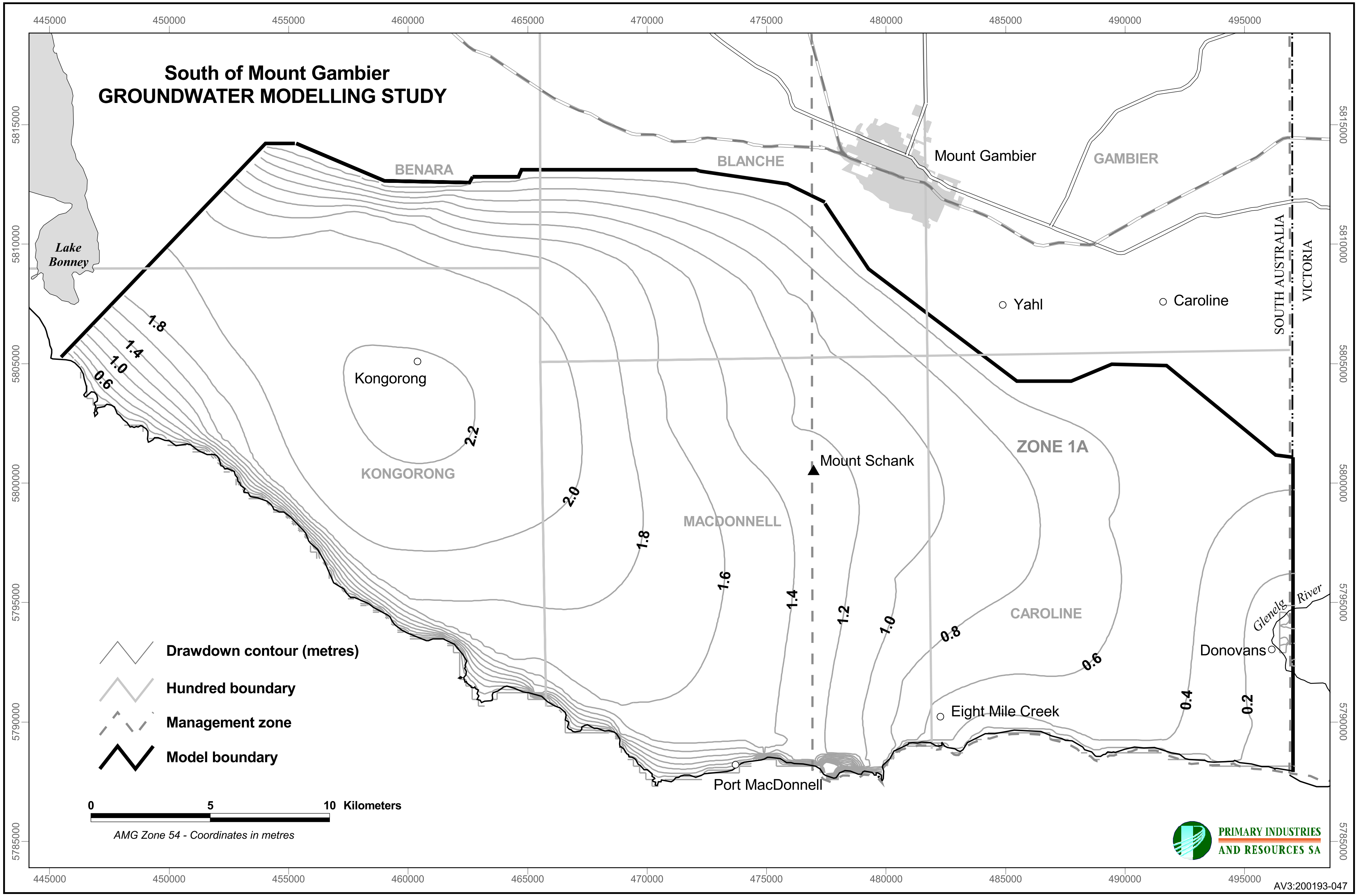
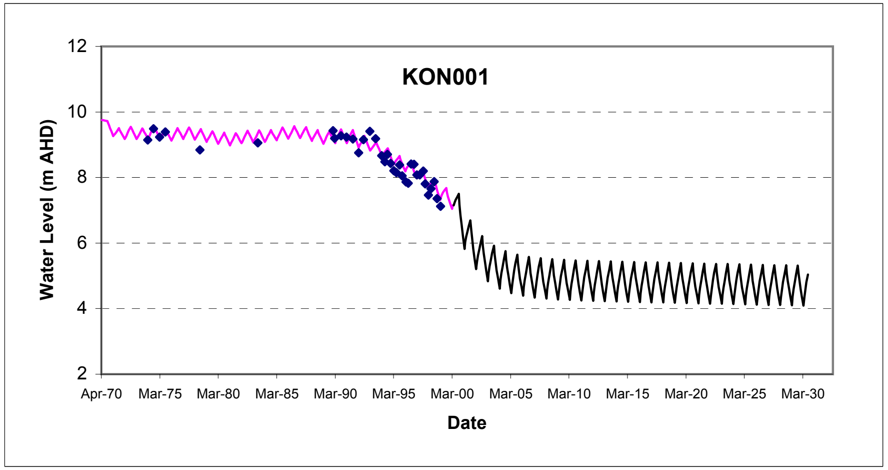
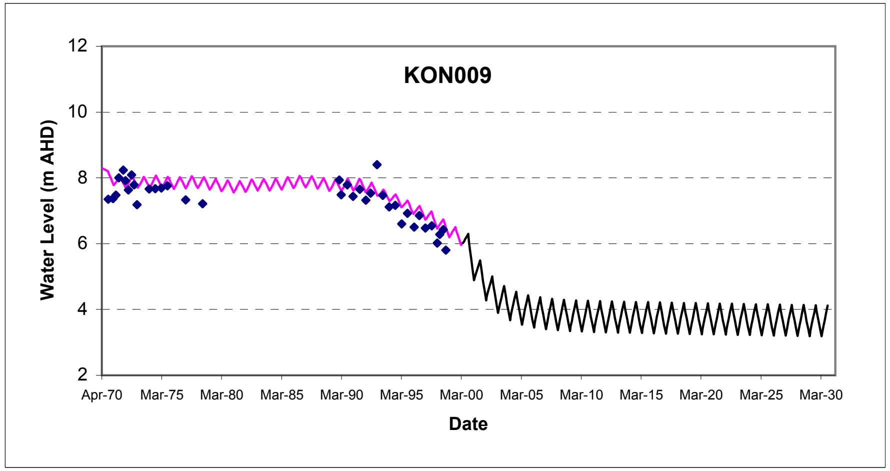
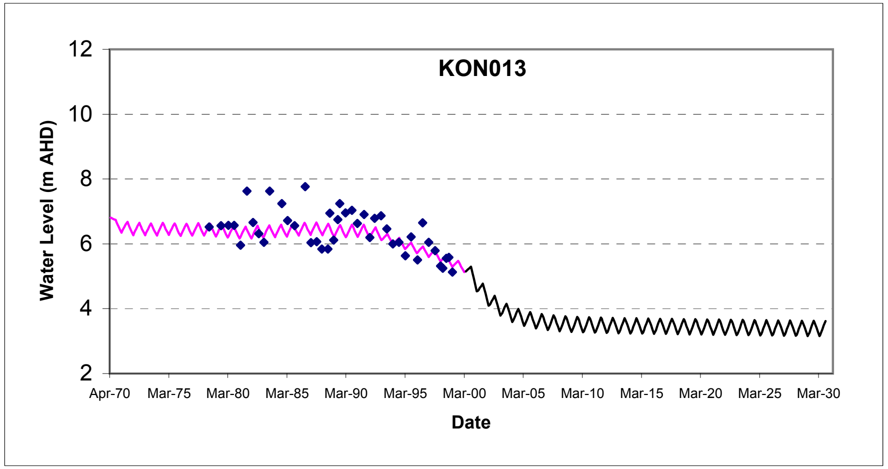
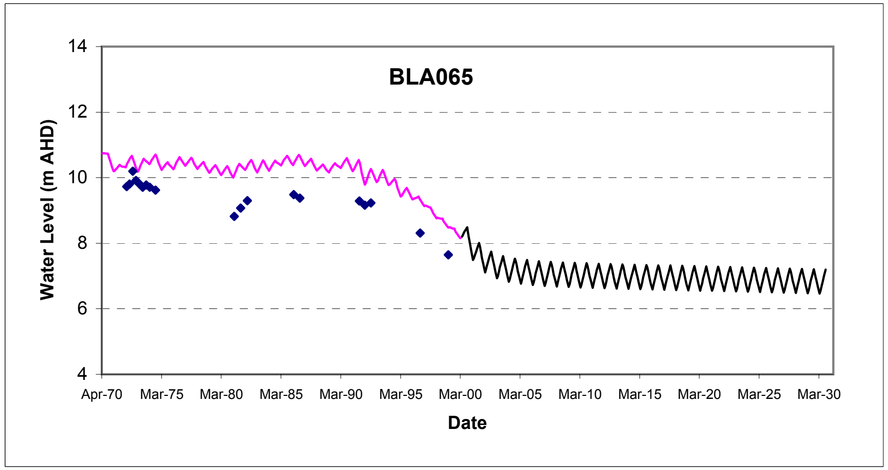


Figure F2-2 *Predicted residual drawdown contours for scenario 6 (2000 to 2030) with small head decline on the northern boundary.*

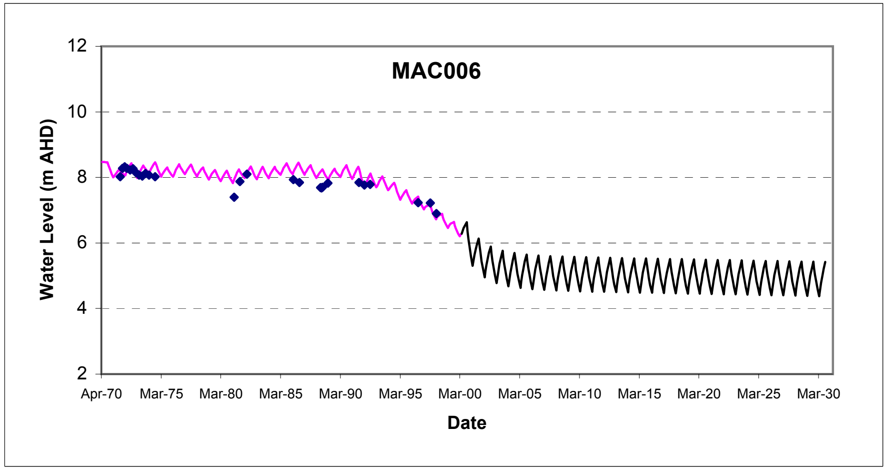


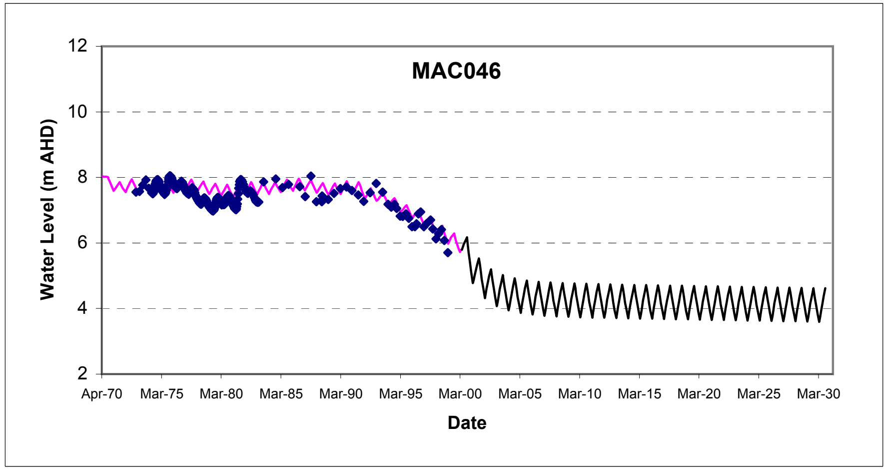


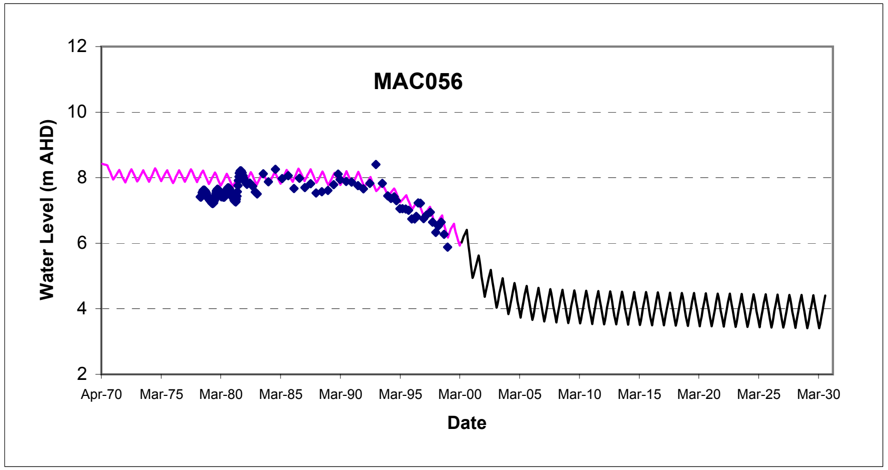


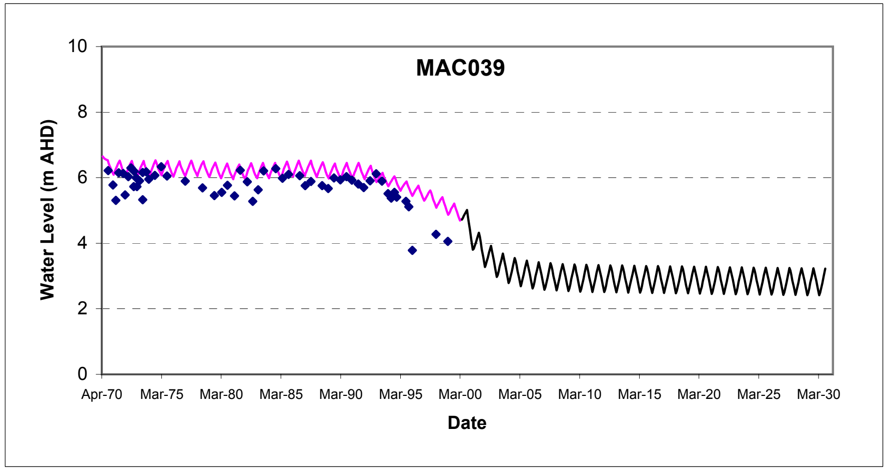


Appendix F2-3 *Hydrographs for Scenario 6 with small head decline on the northern boundary (1970-2030)*

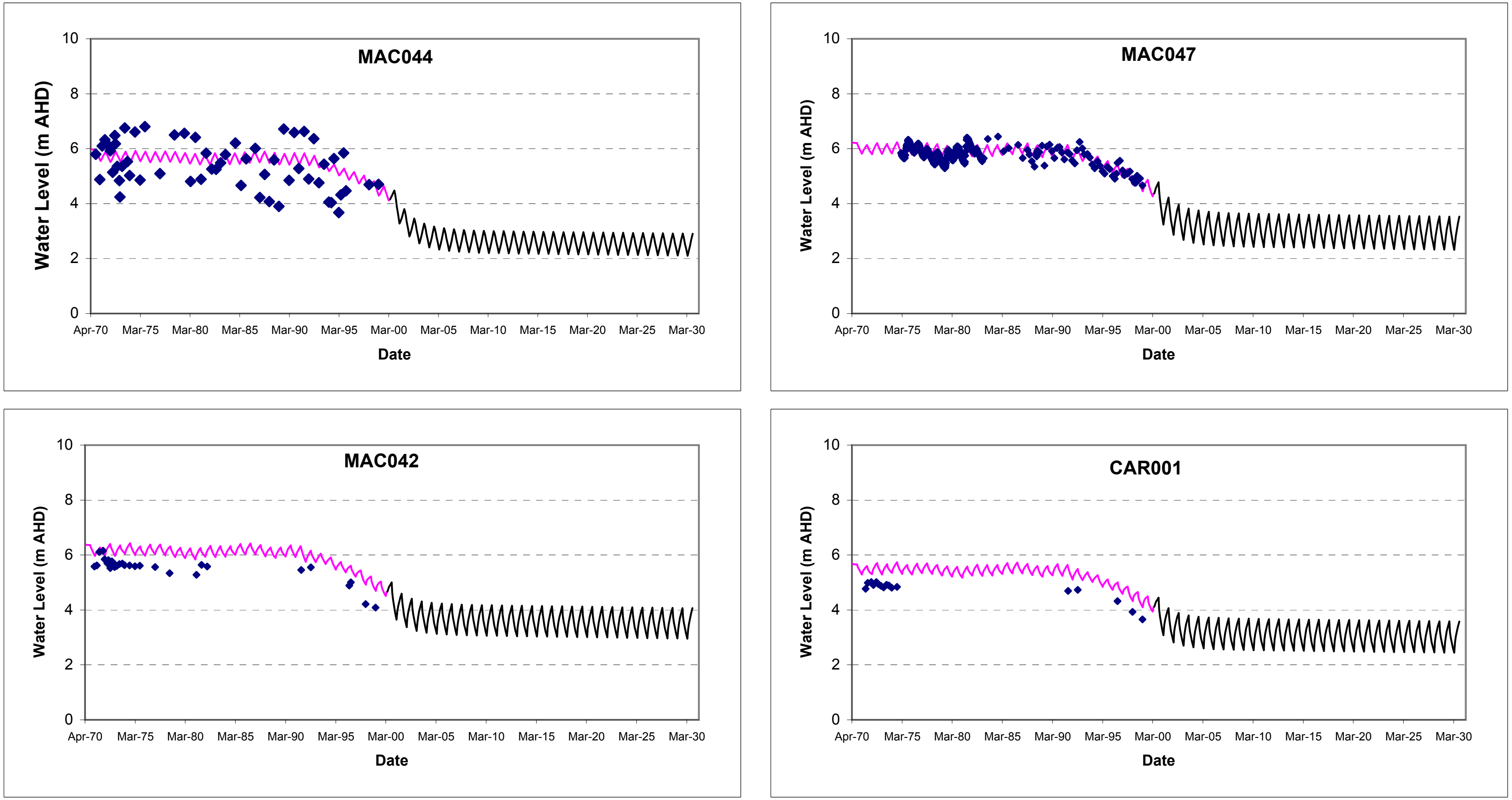




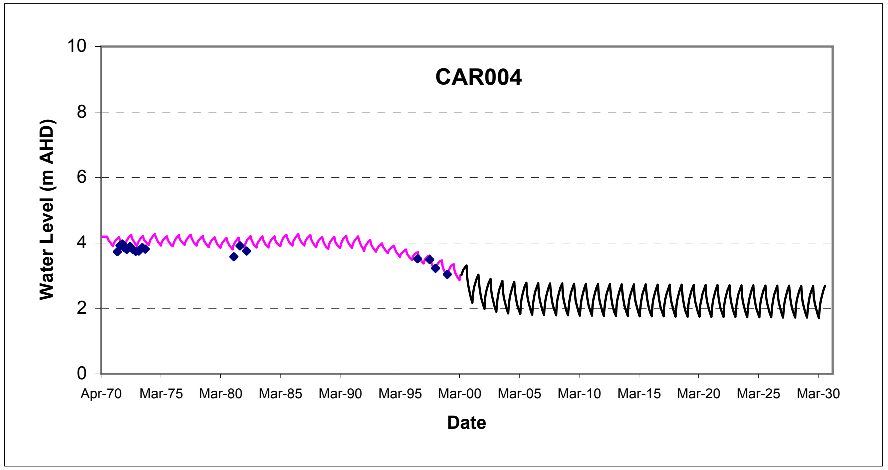


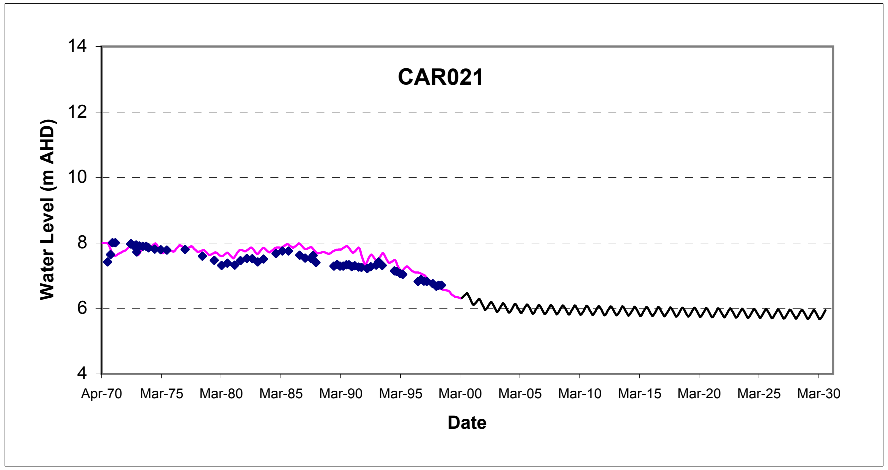


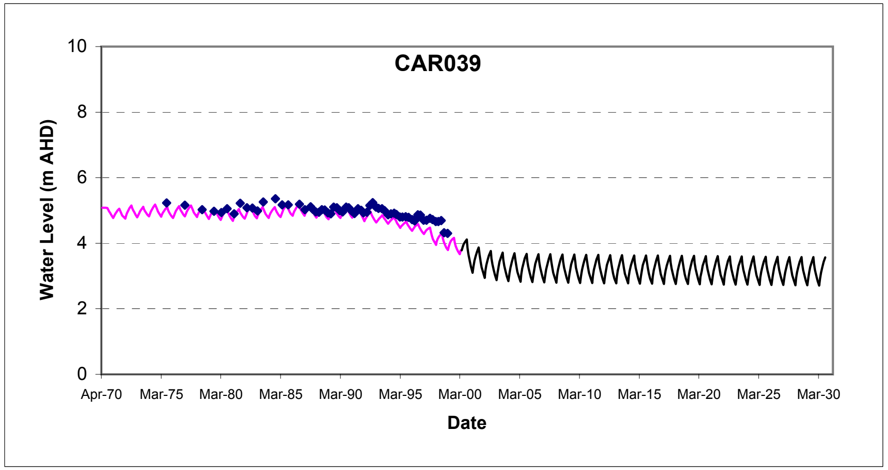
Appendix F2-4 *Hydrographs for Scenario 6 with small head decline on the northern boundary (1970-2030)*

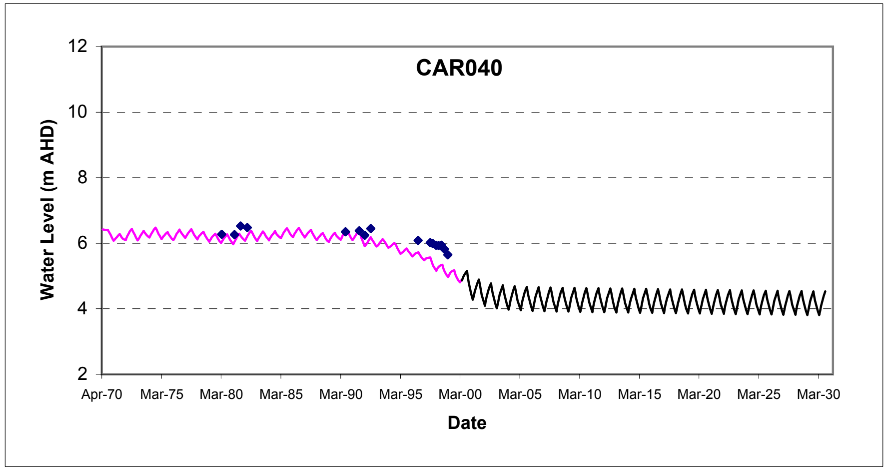


Appendix F2-5 *Hydrographs for Scenario 6 with small head decline on the northern boundary (1970-2030)*









Appendix F2-6 *Hydrographs for Scenario 6 with small head decline on the northern boundary (1970-2030)*

Appendix F3

Scenario 6: Results with a large head decline

on the northern boundary

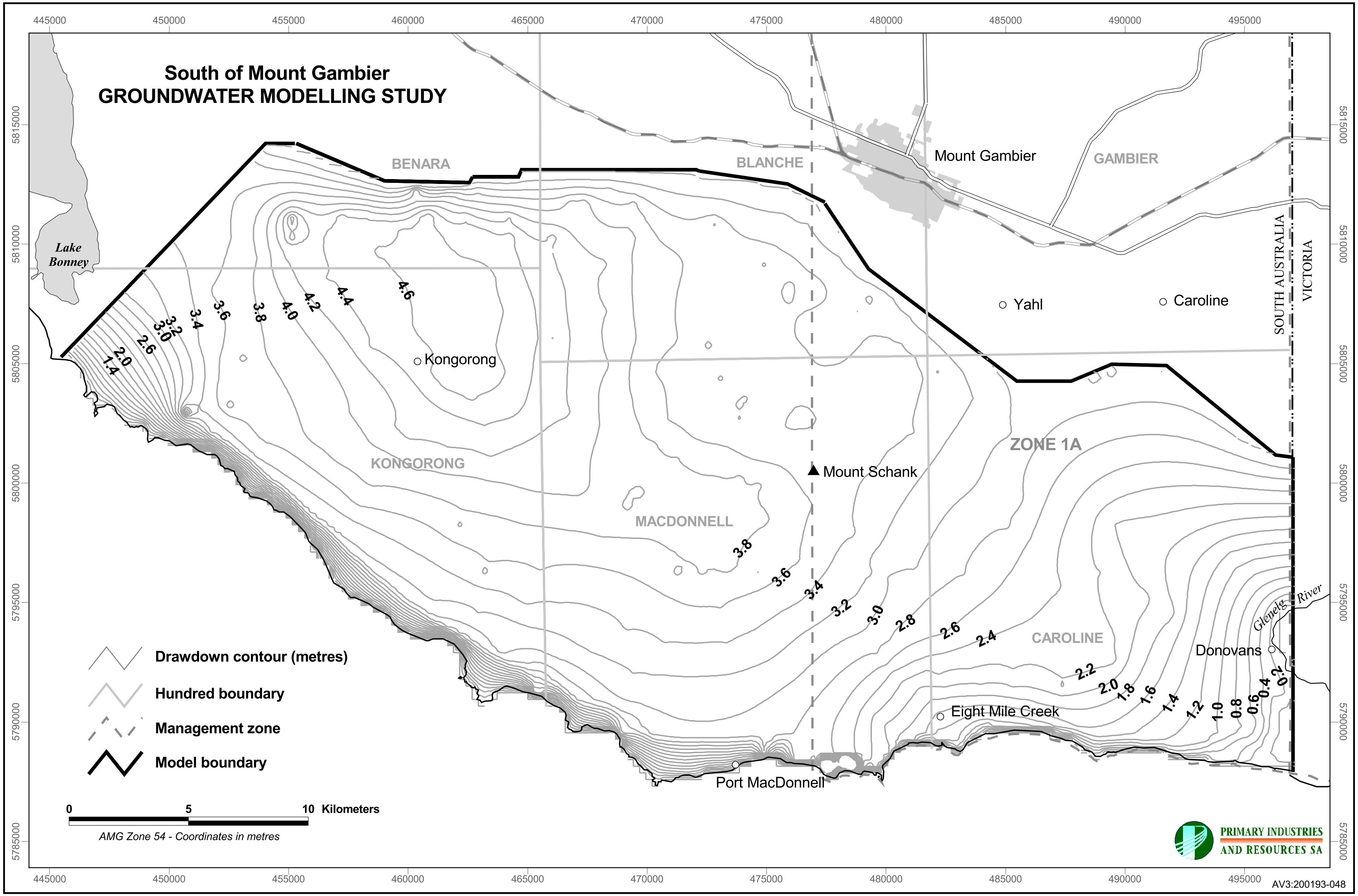


Figure F3-1 Predicted maximum drawdown contours for scenario 6 (2000 to 2030) with large head decline on the northern boundary.

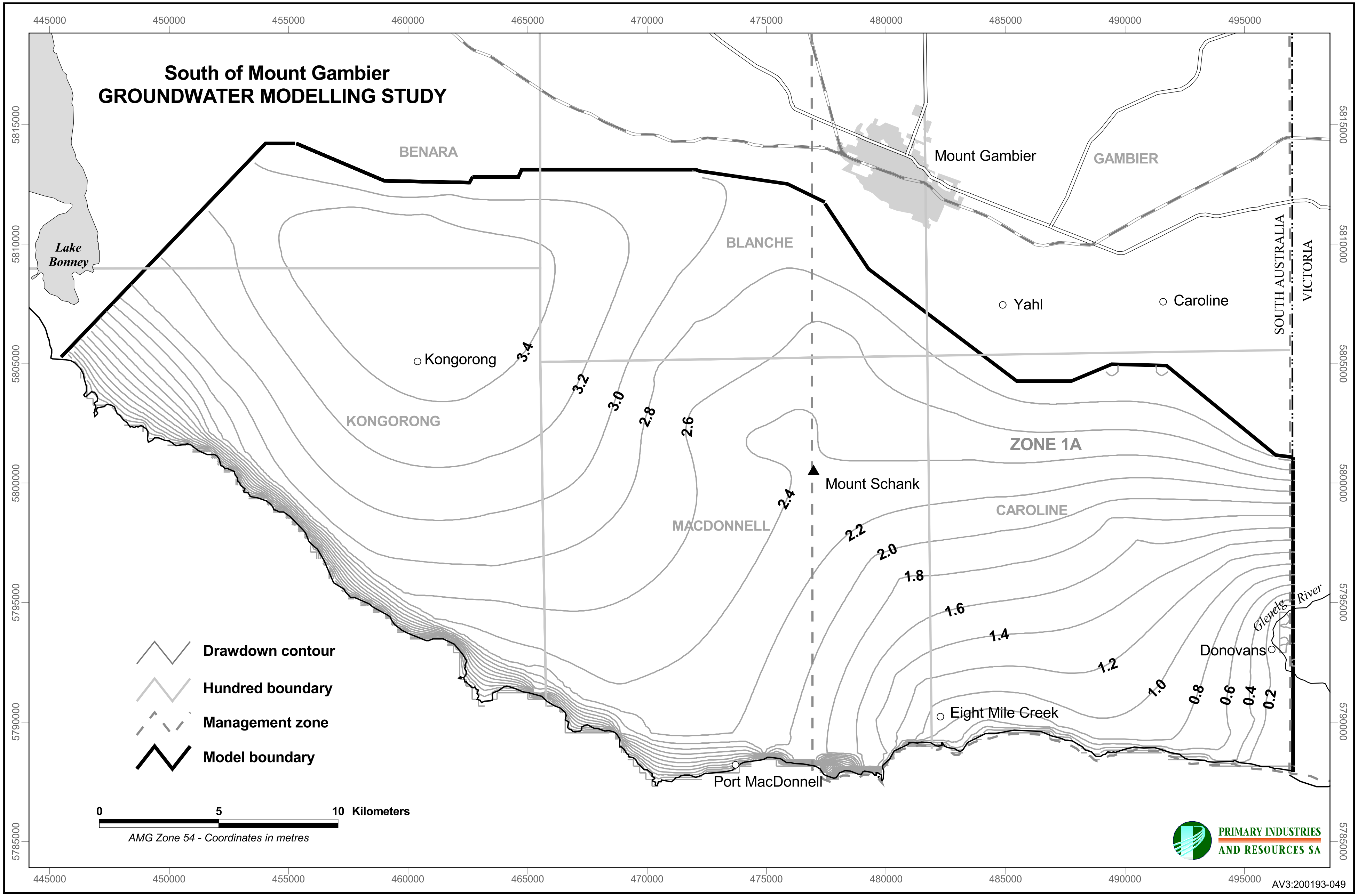
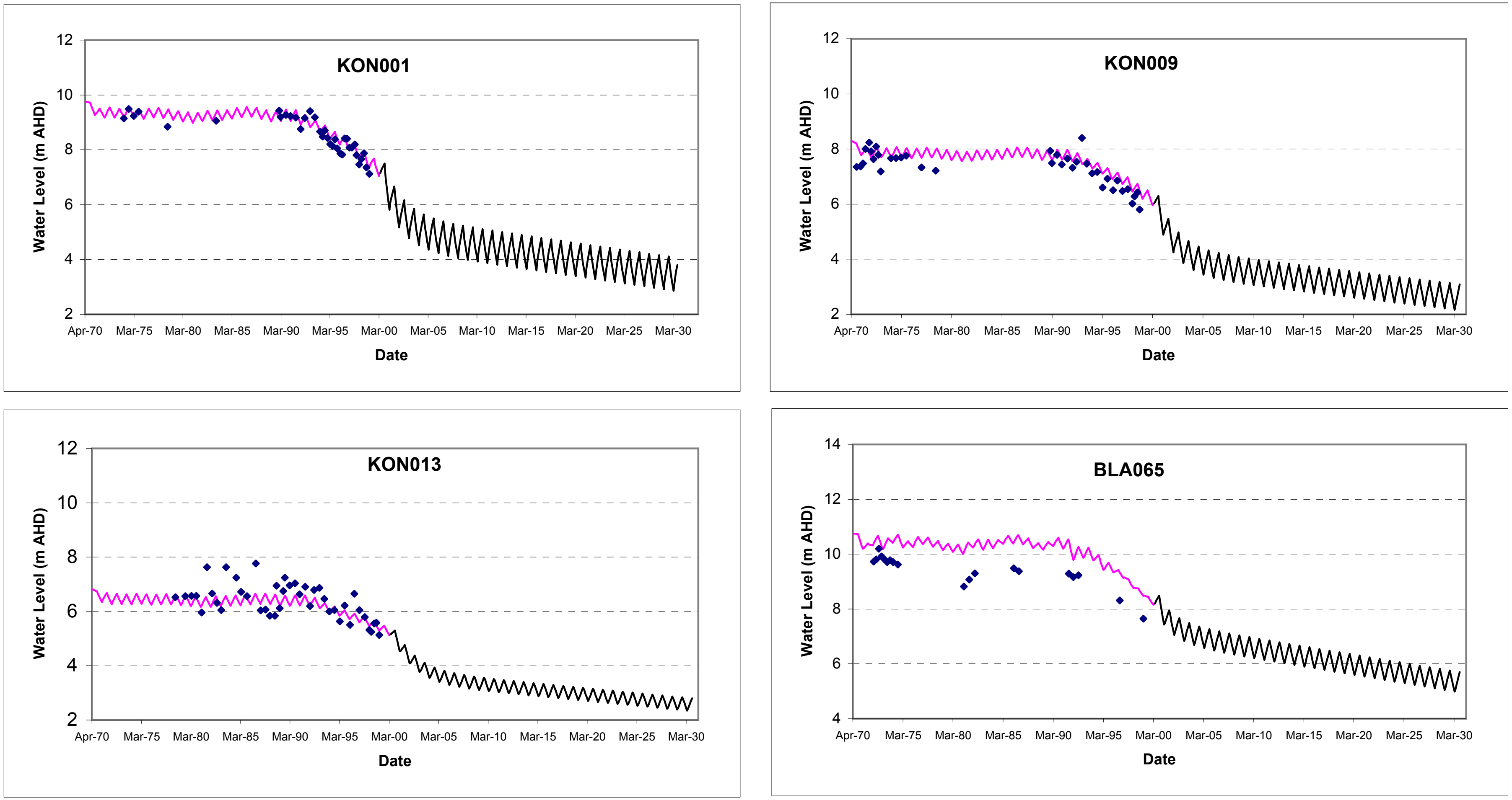
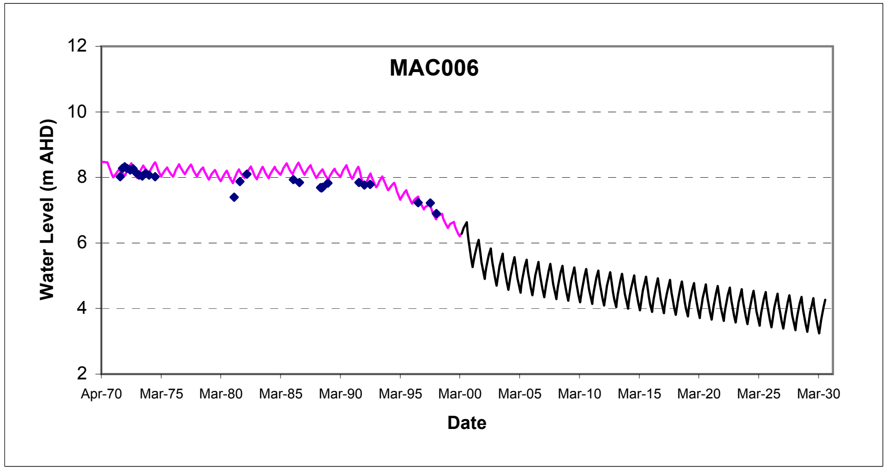
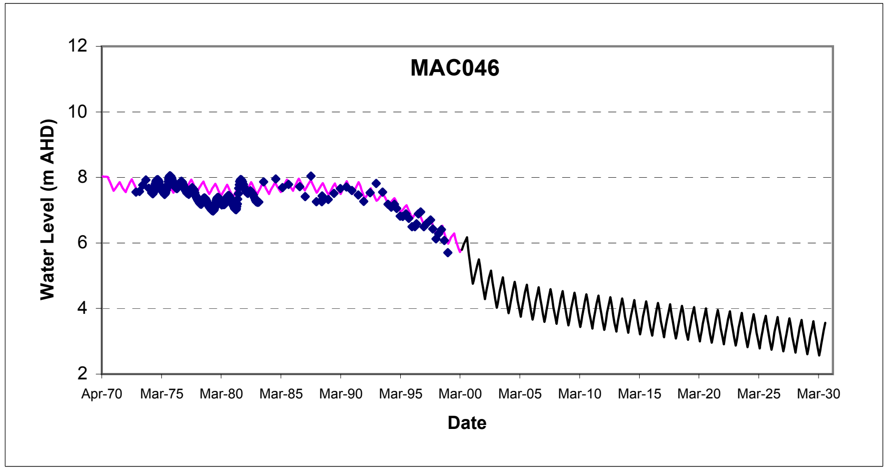


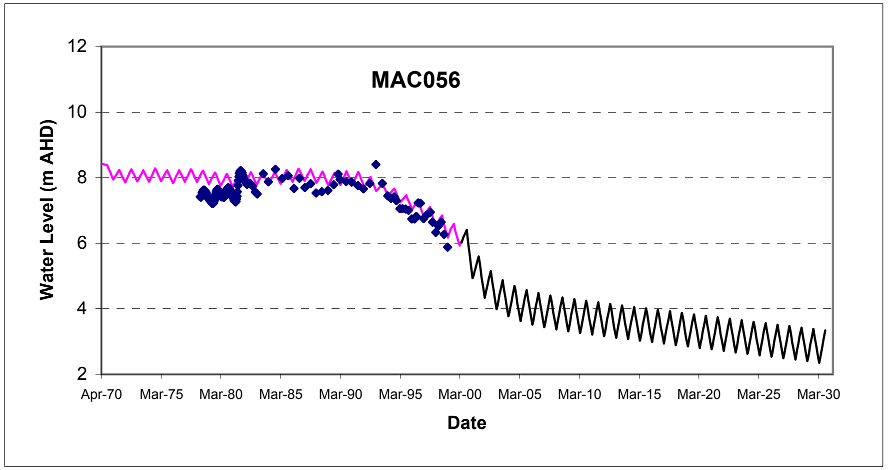
Figure F3-2 *Predicted residual drawdown contours for scenario 6 (2000 to 2030) with large head decline on the northern boundary.*

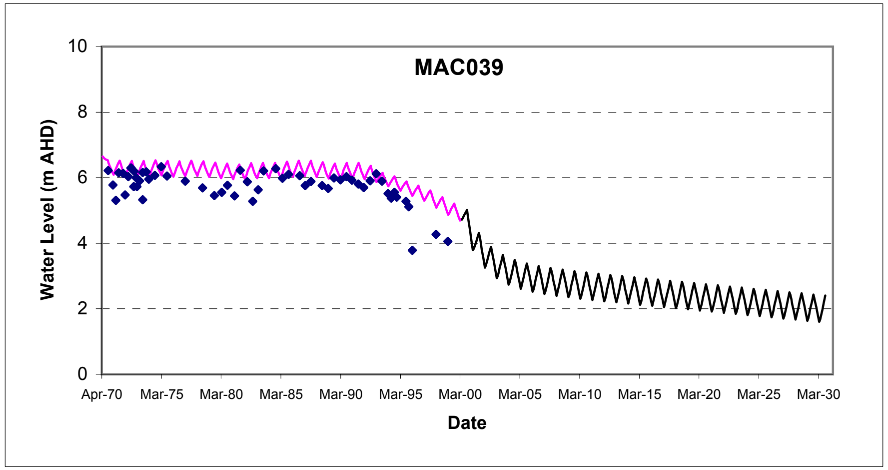


Appendix F3-3 *Hydrographs for Scenario 6 with large head decline on the northern boundary (1970-2030)*

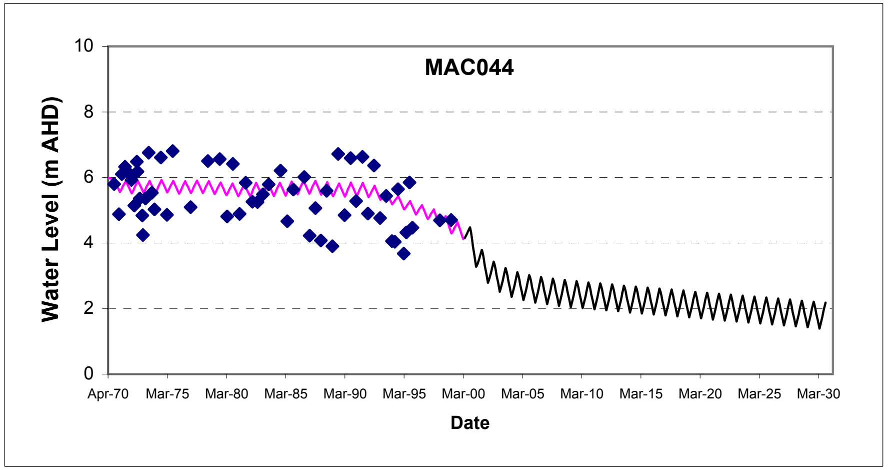


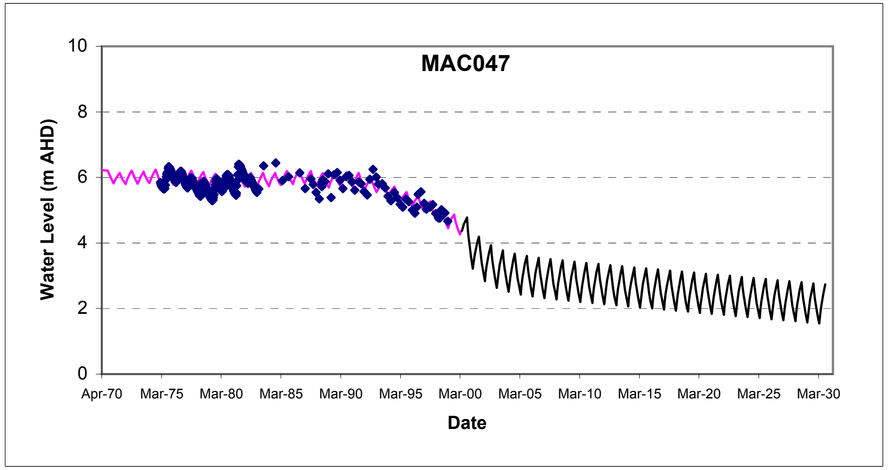


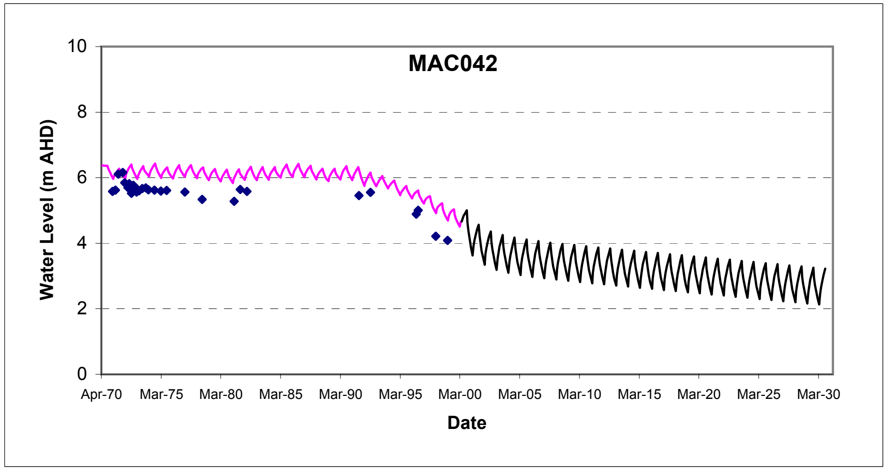


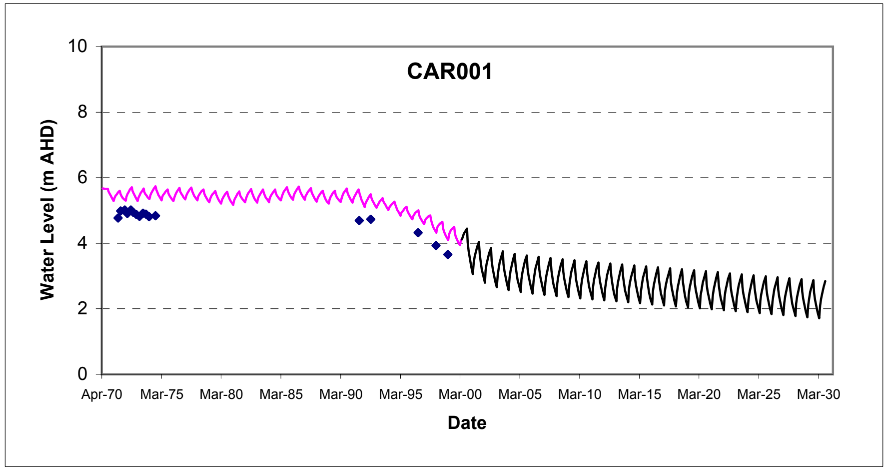


Appendix F3-4 *Hydrographs for Scenario 6 with large head decline on the northern boundary (1970-2030)*

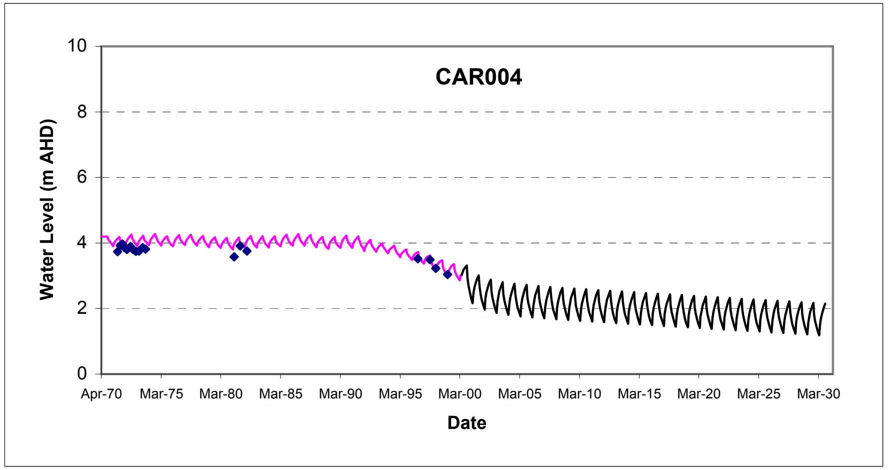


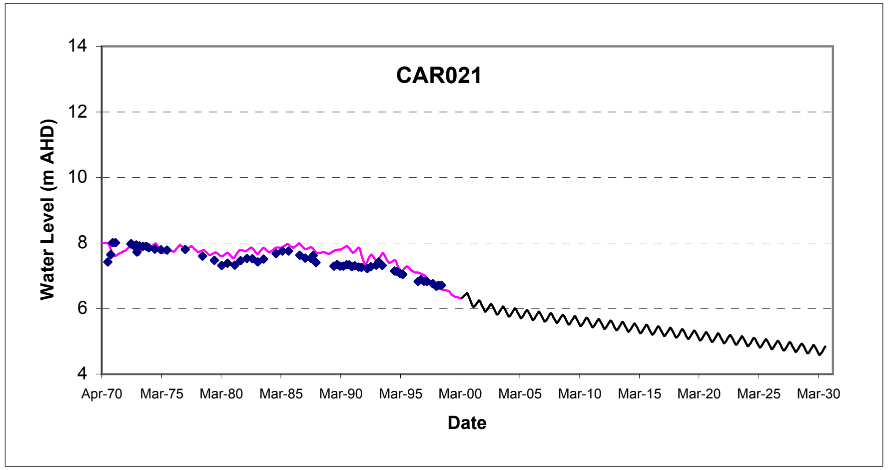


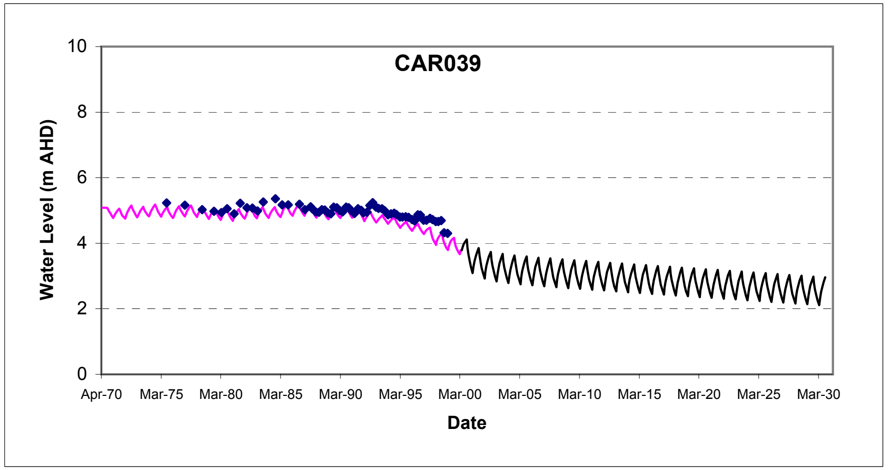


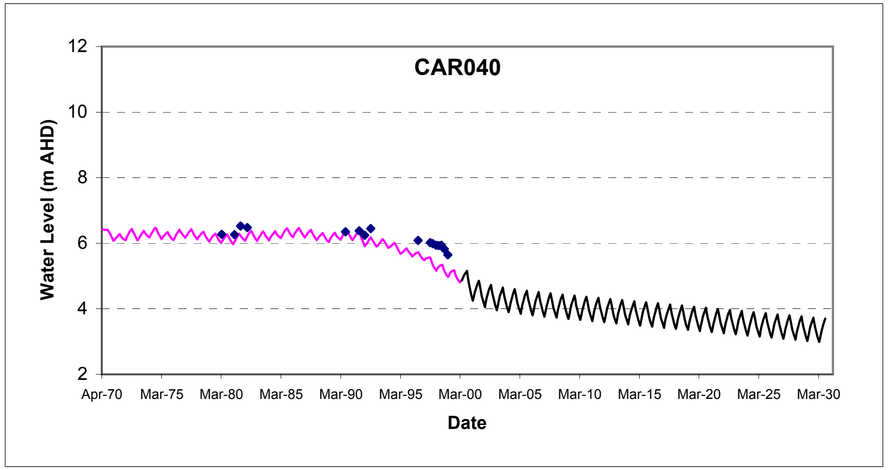


Appendix F3-5 *Hydrographs for Scenario 6 with large head decline on the northern boundary (1970-2030)*









Appendix F3-6 *Hydrographs for Scenario 6 with large head decline on the northern boundary (1970-2030)*

Appendix G

Water budgets for different model scenarios

Appendix G1: *Predicted flow budget with no head decline on the northern boundary*

	FLOW AT END OF CALIBRATION IN THE YEAR 2000 (ML/ year)	FLOWS FOR DIFFERENT SCENARIOS IN THE YEAR 2030 (ML/year)					
		SCENARIO 1	**SCENARIO 2**	**SCENARIO 3**	**SCENARIO 4**	**SCENARIO 5**	**SCENARIO 6**
INFLOW COMPONENTS							
Flow into the area across the northern boundary	149 568	161 472	169 049	172 426	177 508	182 837	193 677
Vertical recharge	35 409	35 409	35 409	35 409	35 409	35 409	35 409
Upward leakage from the confined aquifer	805	802	810	812	817	823	834
TOTAL INFLOW	**185 782**	**197 684**	**205 268**	**208 647**	**213 734**	**219 069**	**229 920**
OUTFLOW COMPONENTS							
Discharge from the springs	96 310	95 614	91 215	90 109	87 050	83 948	77 626
Discharge to the sea	58 260	56 295	52 244	50 613	47 665	44 632	38 302
Evapotranspiration loss	4932	3900	2294	1616	943	423	100
Extraction (Irrigation)	24 593	24 593	42 898	49 819	62 226	74 671	99 562
Discharge to the Glenelg River	17 053	16 859	16 306	16 224	15 899	15574	14 917
TOTAL OUTFLOW	**201 148**	**197 261**	**204 957**	**208 382**	**213 783**	**219 249**	**230 507**
VARIATION BETWEEN INFLOW and OUTFLOW (%)	-8.27	0.21	0.15	0.13	-0.02	-0.08	-0.26

Appendix G2: *Predicted flow budget with a small head decline on the northern boundary*

	FLOW AT END OF CALIBRATION IN THE YEAR 2000 (ML/ year)	FLOWS FOR DIFFERENT SCENARIOS IN THE YEAR 2030 (ML/year)					
		SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
INFLOW COMPONENTS							
Flow into the area across the northern boundary	149 568	155 466	163 074	16 6471	17 1574	176 927	187 804
Vertical recharge	35 409	35 409	35 409	35 409	35 409	35 409	35 409
Upward leakage from the confined aquifer	805	811	818	820	826	831	842
TOTAL INFLOW	**185 782**	**191 685**	**199 301**	**202 700**	**207 809**	**213 168**	**224 055**
OUTFLOW COMPONENTS							
Discharge from the springs	96 310	92 870	88 448	87 333	84 255	81 137	74 792
Discharge to the sea	58 260	54 878	50 770	49 106	46 121	43 054	36 660
Evapotranspiration loss	4932	3397	1918	1304	713	336	64
Extraction (Irrigation)	24 593	24 593	42 898	49 819	62 226	74 671	99 562
Discharge to the Glenelg River	17 053	15 961	15 407	15 175	15 001	14 674	14 015
TOTAL OUTFLOW	**201 148**	**191 700**	**199 441**	**202 736**	**208 315**	**213 871**	**225 093**
VARIATION BETWEEN INFLOW and OUTFLOW (%)	-8.27	-0.01	-0.07	-0.02	-0.24	-0.33	-0.46

Appendix G3: *Predicted flow budget with a large head decline on the northern boundary*

	FLOW AT END OF CALIBRATION IN THE YEAR 2000 (ML/ year)	FLOWS FOR DIFFERENT SCENARIOS IN THE YEAR 2030 (ML/year)					
		SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
INFLOW COMPONENTS							
Flow into the area across the northern boundary	149 568	121 861	129 653	133 145	138 375	143 838	154 800
Vertical recharge	35 409	35 409	35 409	35 409	35 409	35 409	35 409
Upward leakage from the confined aquifer	805	858	866	868	874	874	890
TOTAL INFLOW	**185 782**	**158 127**	**165 928**	**169 422**	**174 657**	**180 121**	**191 099**
OUTFLOW COMPONENTS							
Discharge from the springs	96 310	77 314	72 764	71 585	68 420	65 225	58 814
Discharge to the sea	58 260	46 614	42 191	40 364	37 172	33 922	27 369
Evapotranspiration loss	4932	1244	448	207	73	23	1
Extraction (Irrigation)	24 593	24 593	42 898	49 819	62 226	74 671	99 562
Discharge to the Glenelg River	17 053	10 906	10 347	10 263	9936	9606	8947
TOTAL OUTFLOW	**201 148**	**160 671**	**168 648**	**172 238**	**177 826**	**183 448**	**194 691**
VARIATION BETWEEN INFLOW and OUTFLOW (%)	-8.27	-1.61	-1.64	-1.66	-1.81	-1.85	-1.88

Figures

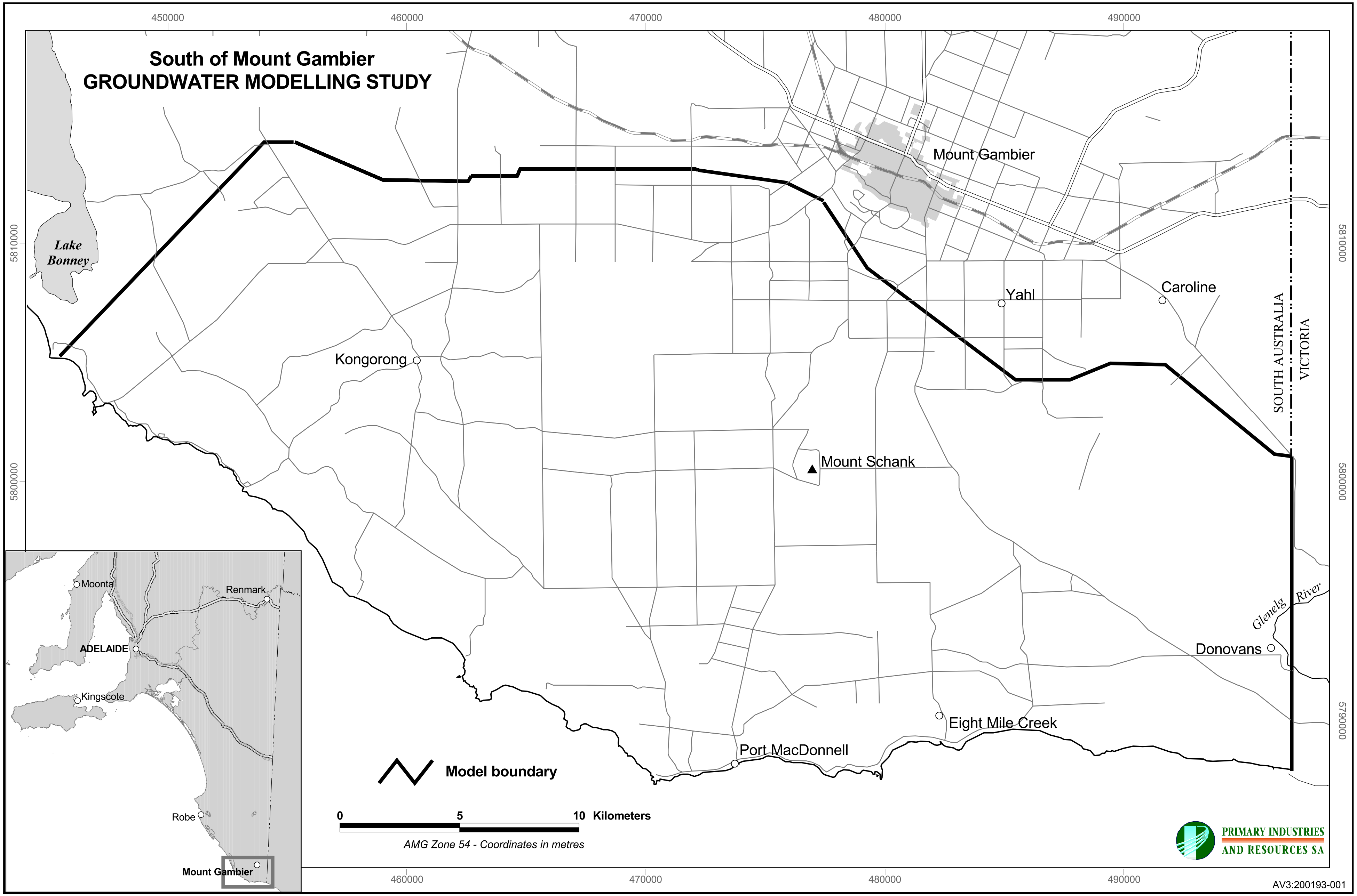


Figure 1 *Location plan and extent of model area.*

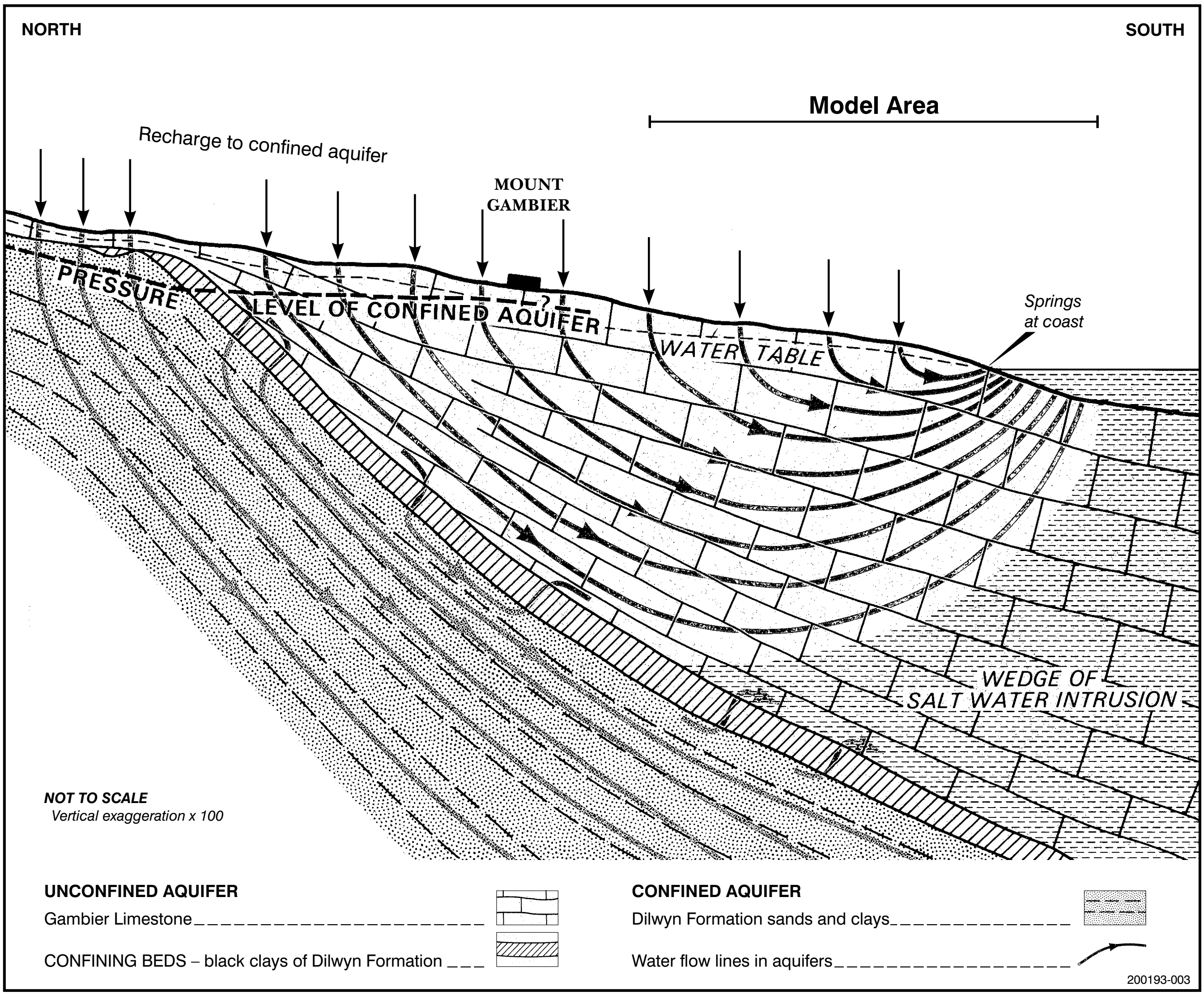


Figure 2 *Hydrogeological cross section Mount Gambier area.*

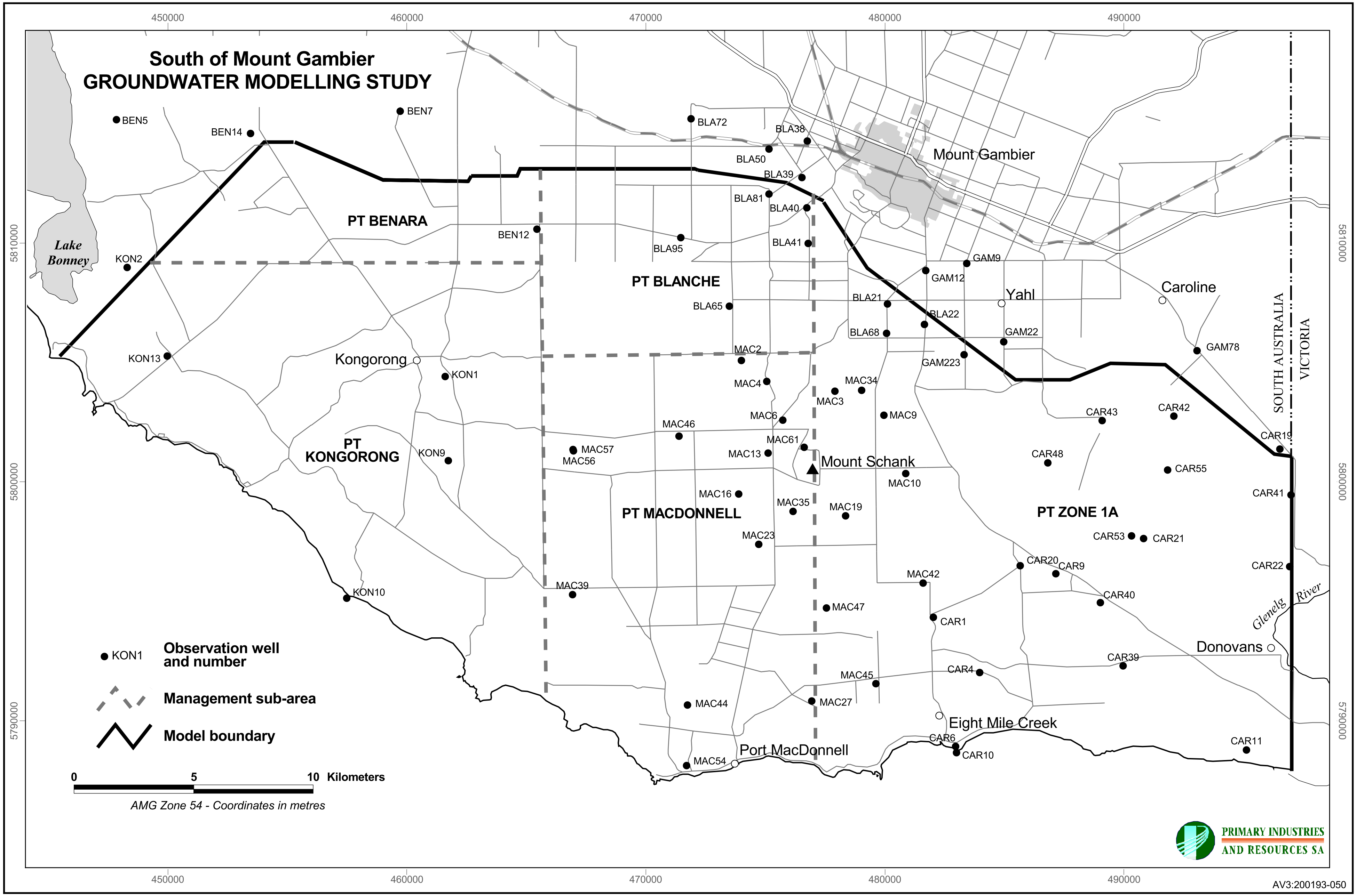


Figure 3 *Location of management sub-areas and observation wells.*

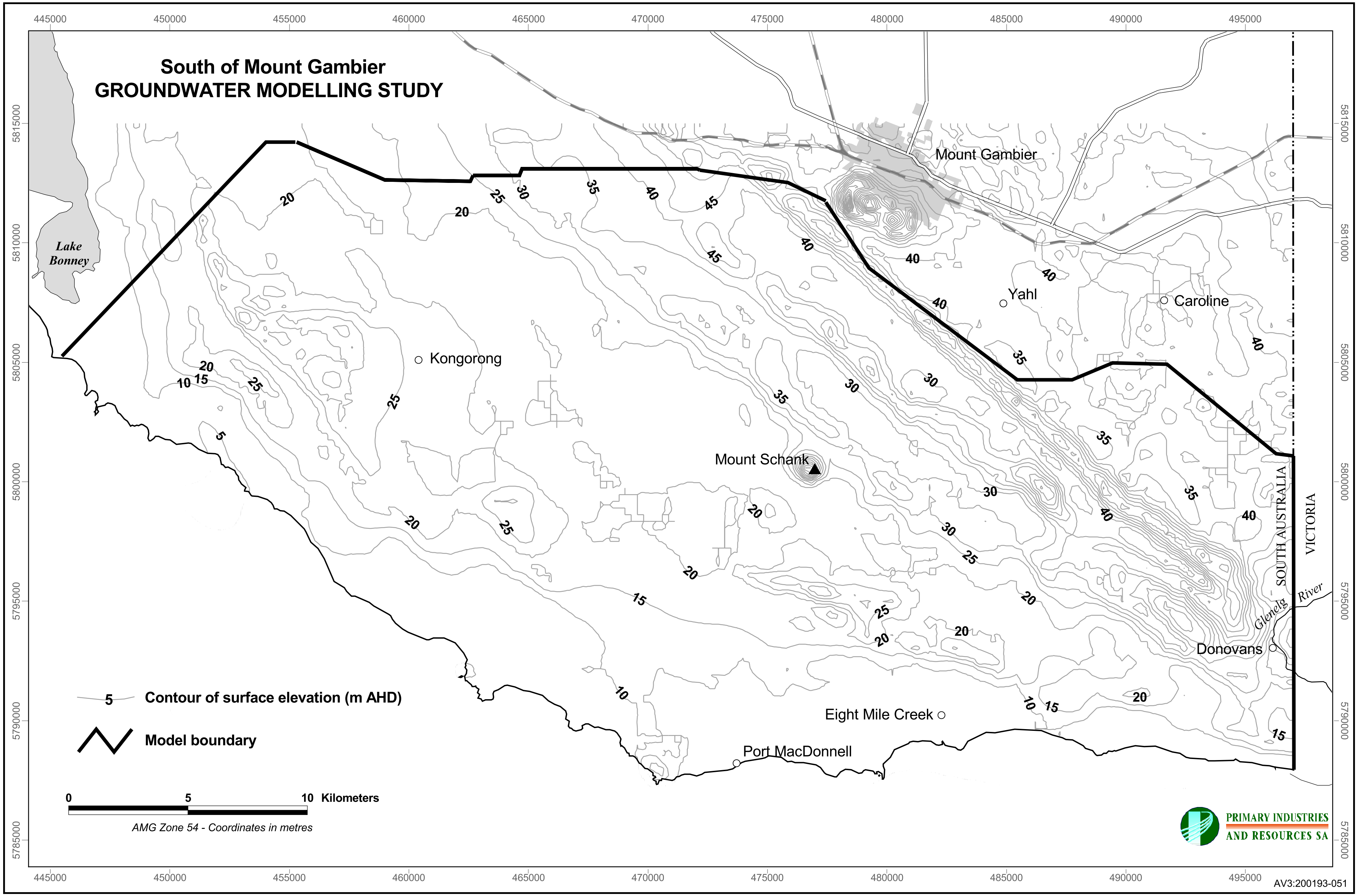


Figure 4 *Ground surface elevation contours.*

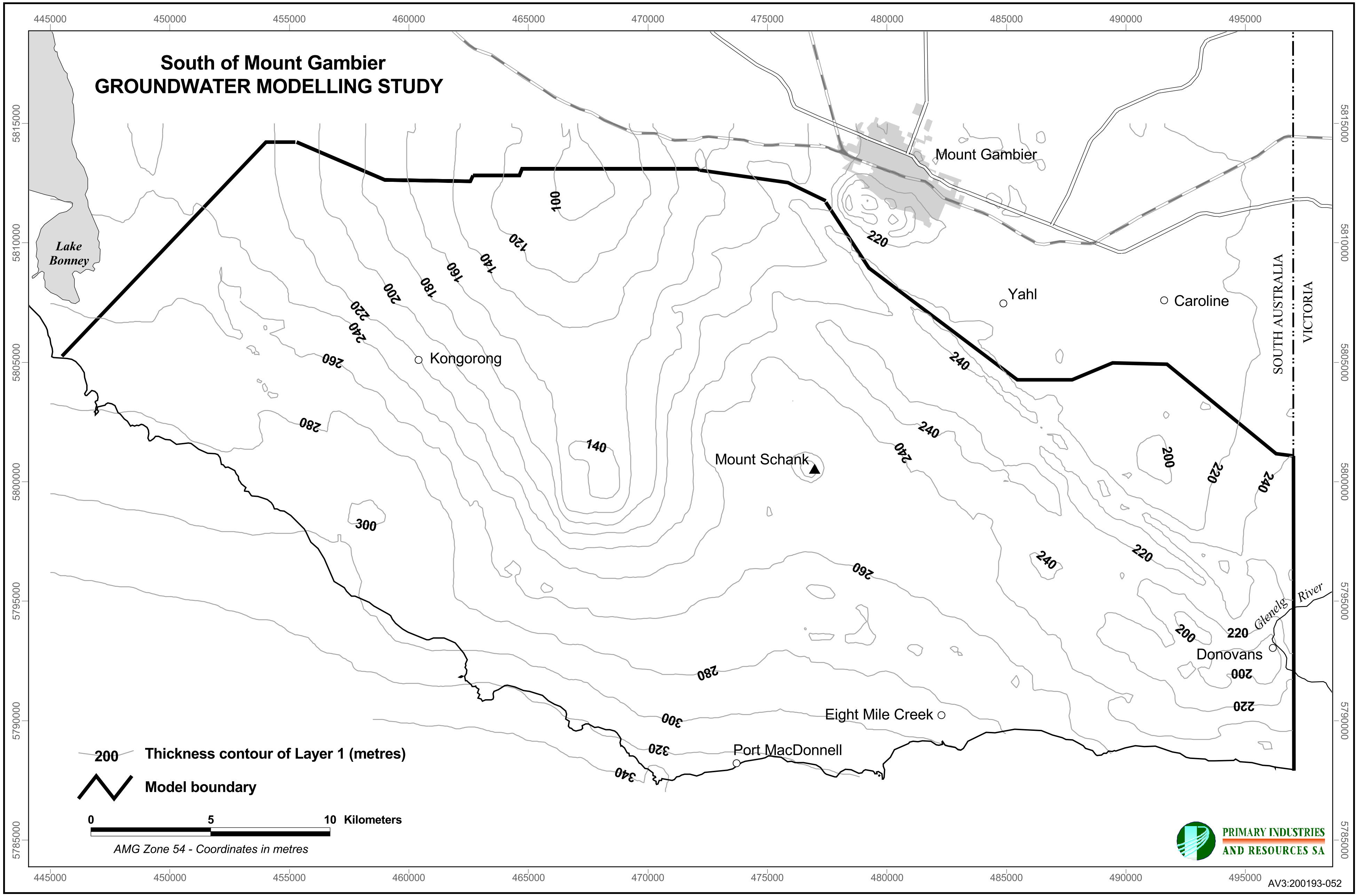


Figure 5 *Thickness contours of Layer 1 (unconfined aquifer).*

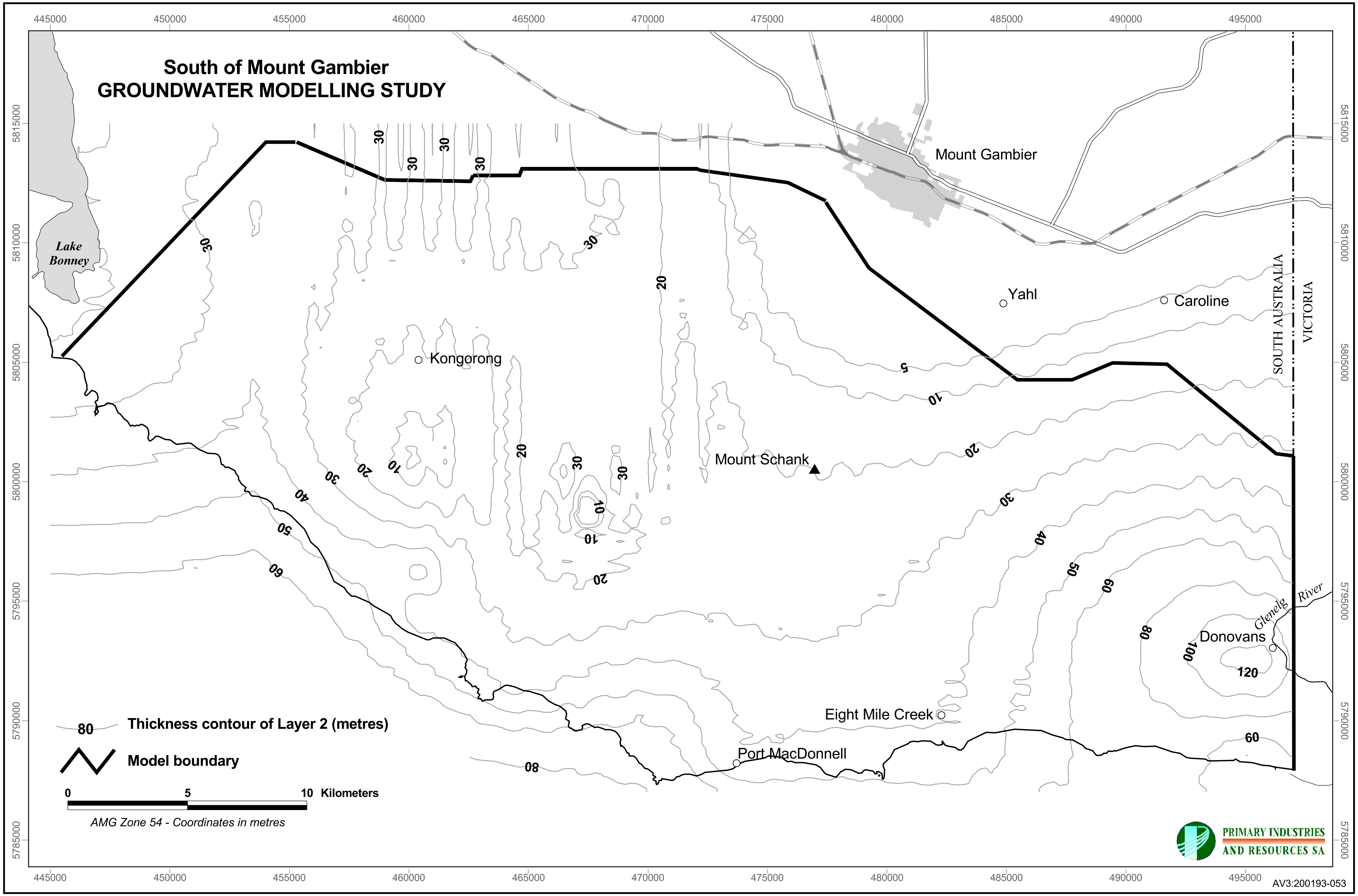


Figure 6 Thickness contours of Layer 2 (aquitard).

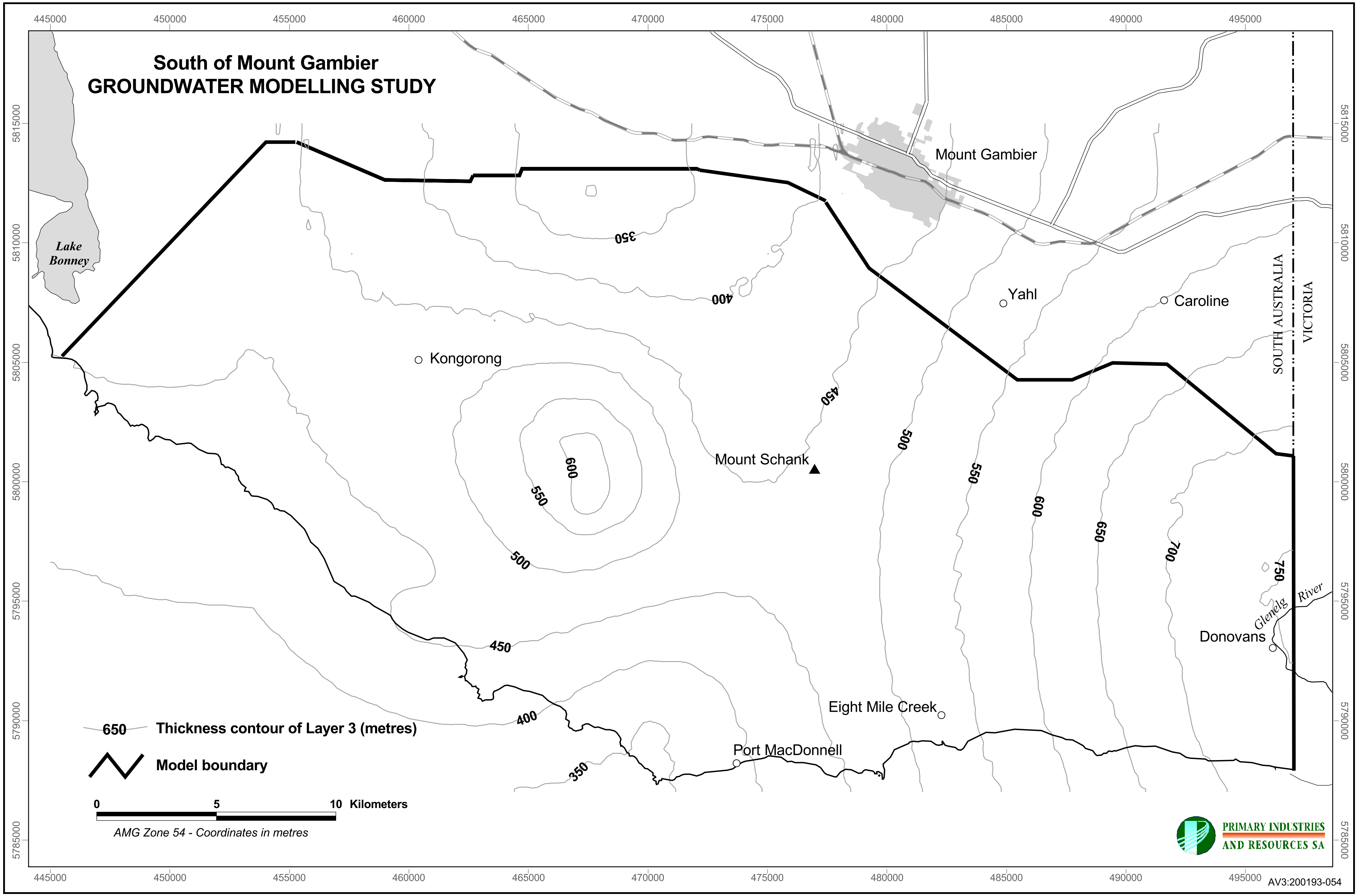


Figure 7 *Thickness contours of Layer 3 (confined aquifer).*

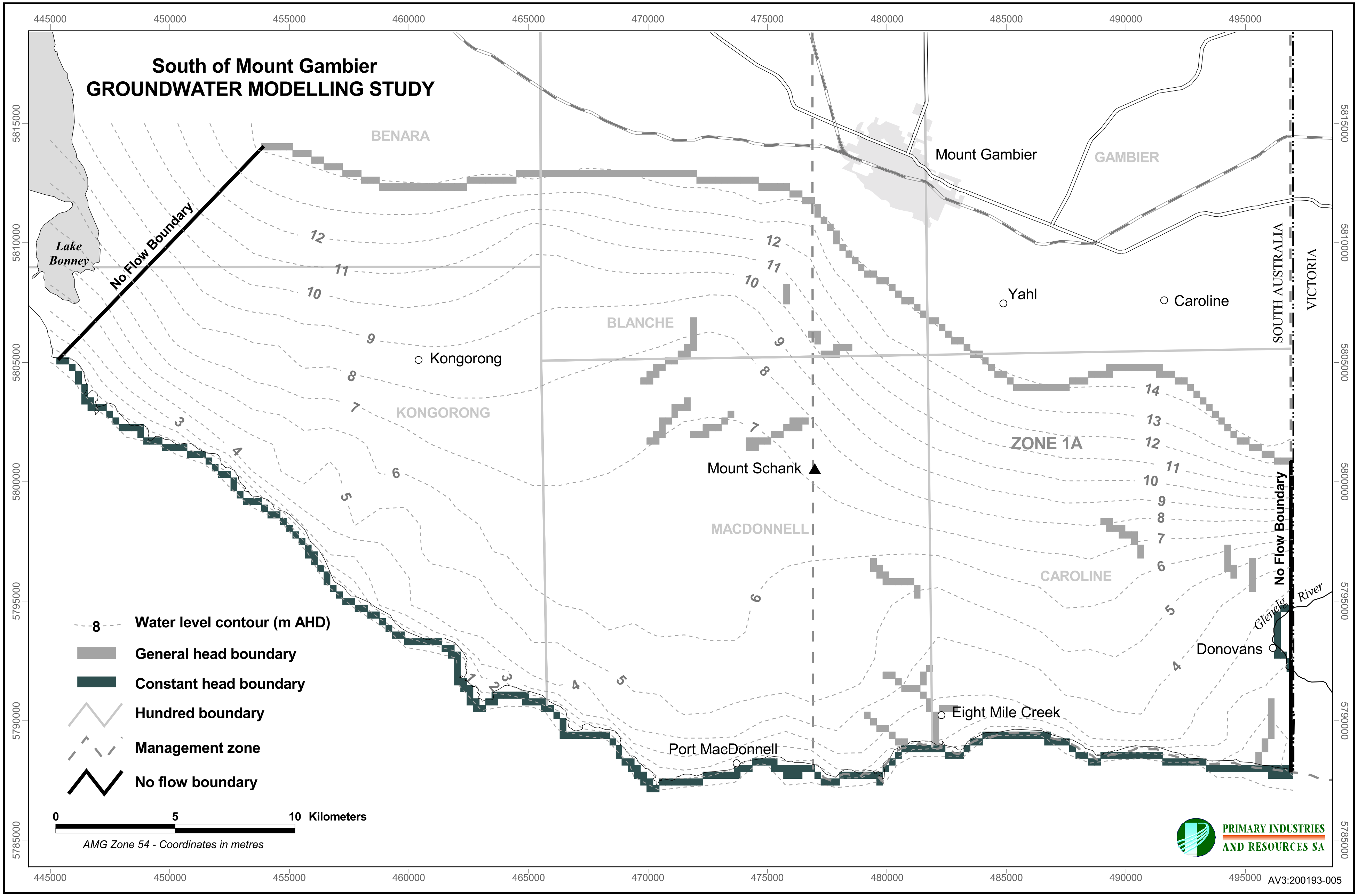


Figure 8 *Boundary conditions and 1996 water level contours for the unconfined aquifer.*

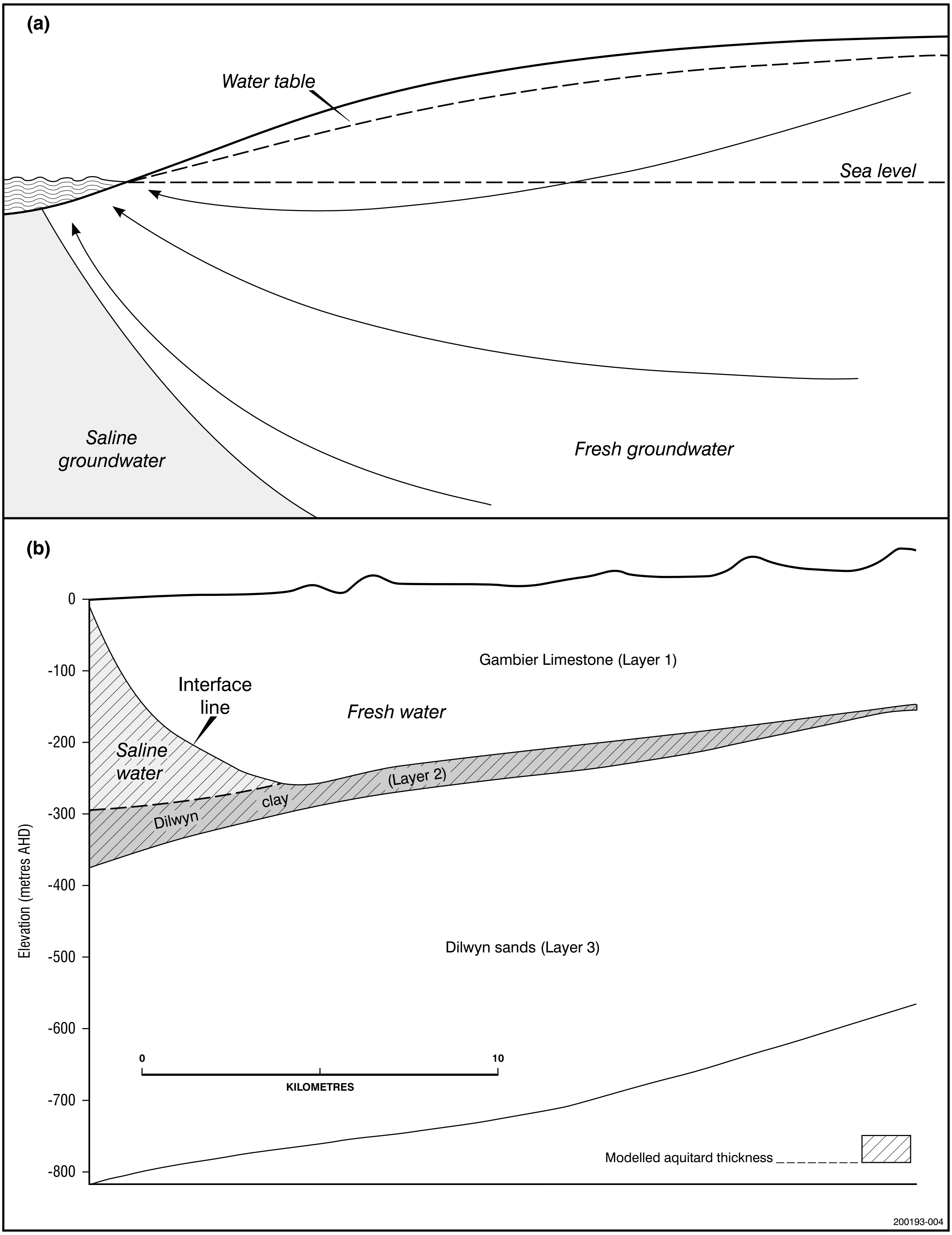


Figure 9 **(a)** *Conceptual saline water and fresh water interface.* **(b)** *Modelled saline water and fresh water interface.*

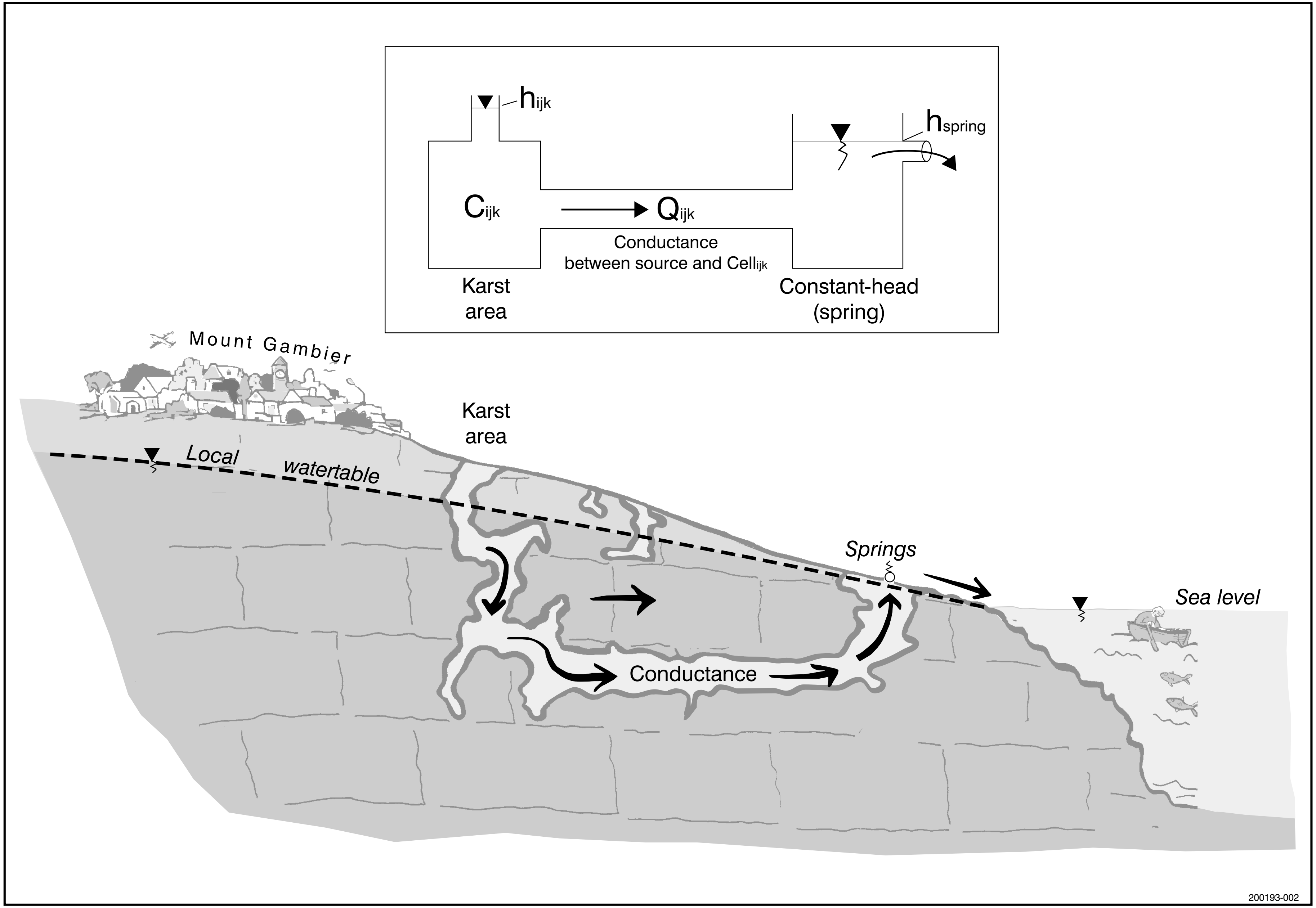


Figure 10 *Conceptualised general head boundary to simulate conduit flow*

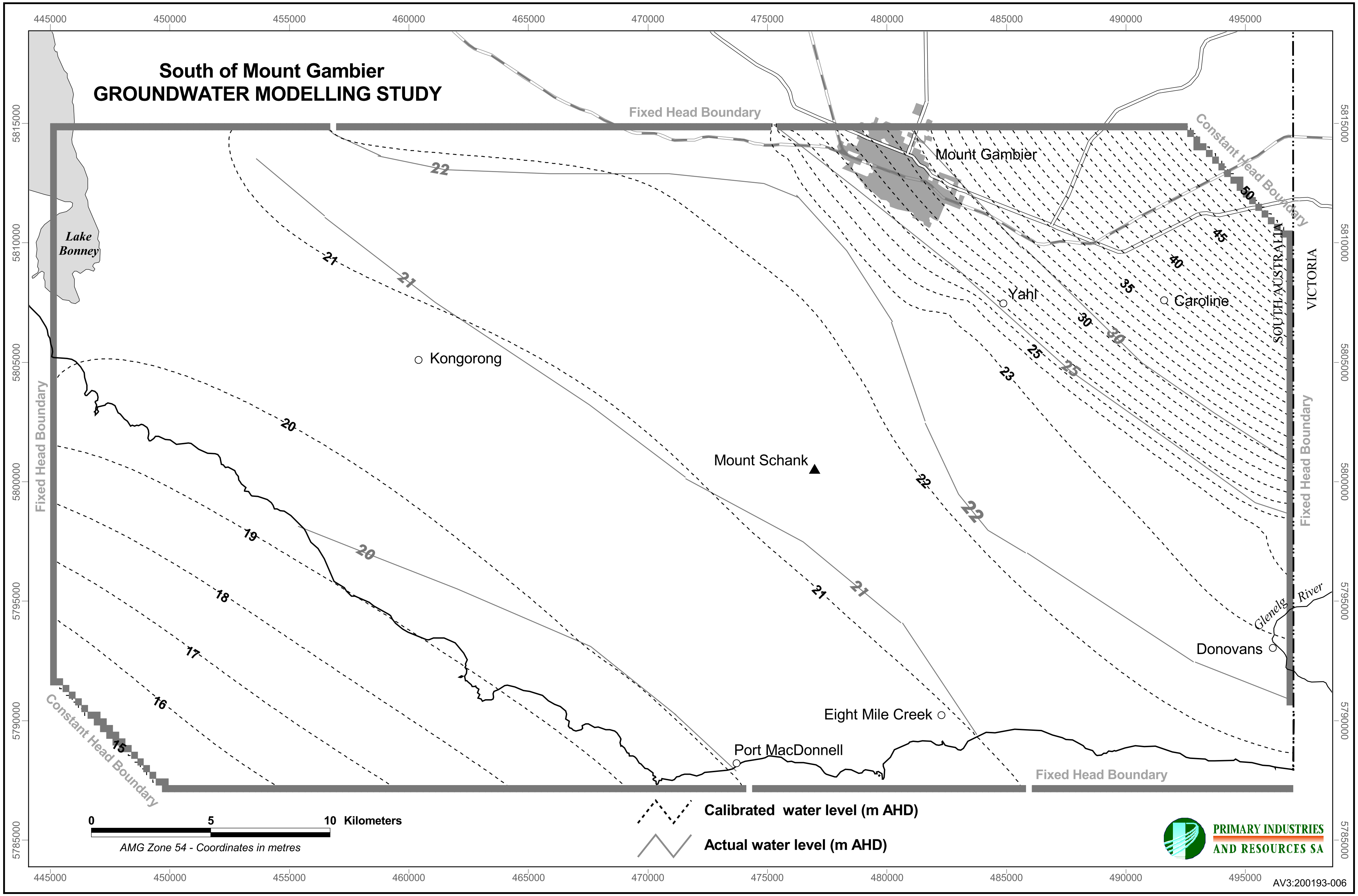


Figure 11 *Boundary conditions and potentiometric level contours (actual and calibrated) for the confined aquifer.*

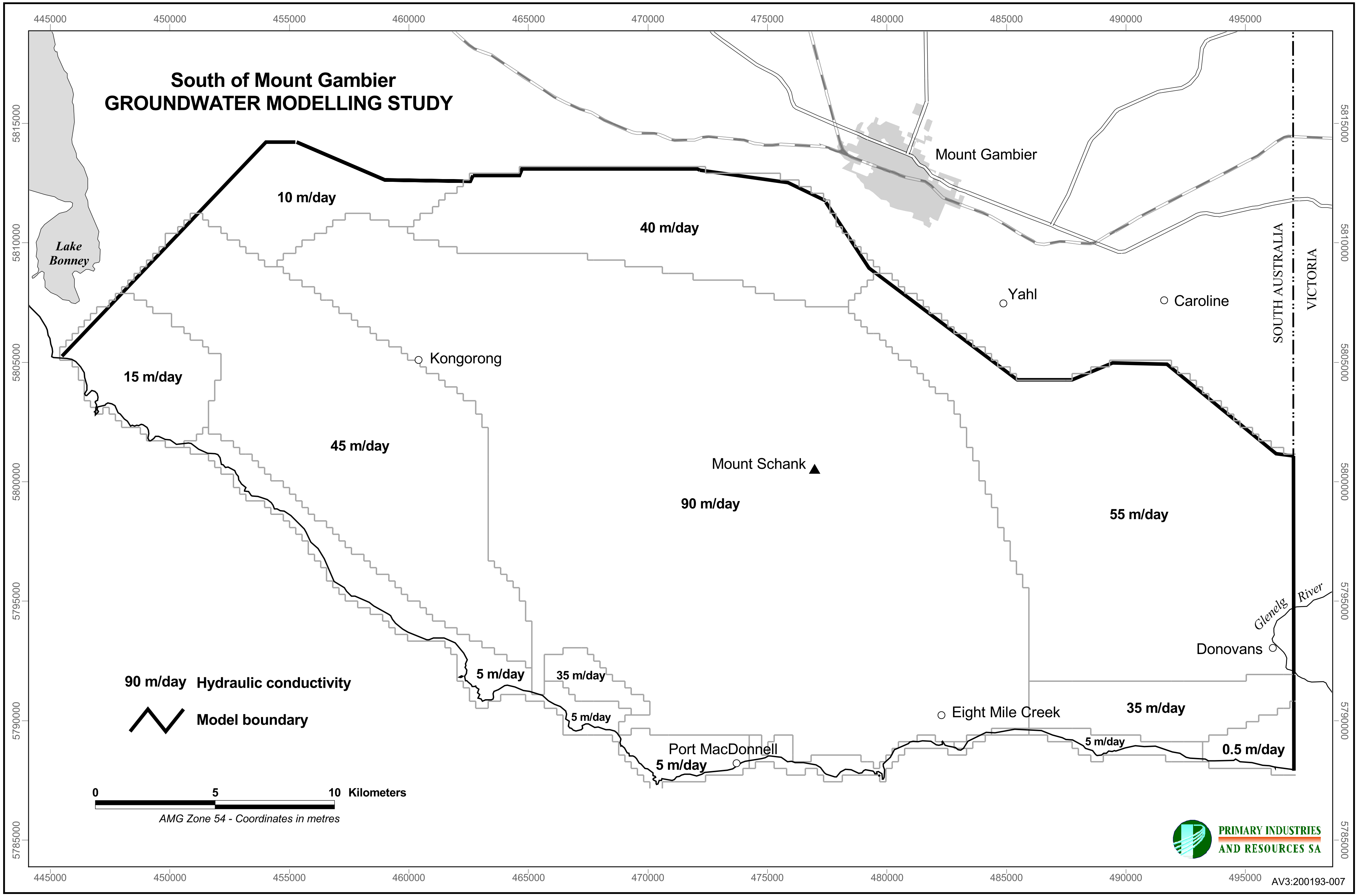


Figure 12 *Zones and hydraulic conductivities for the unconfined aquifer.*

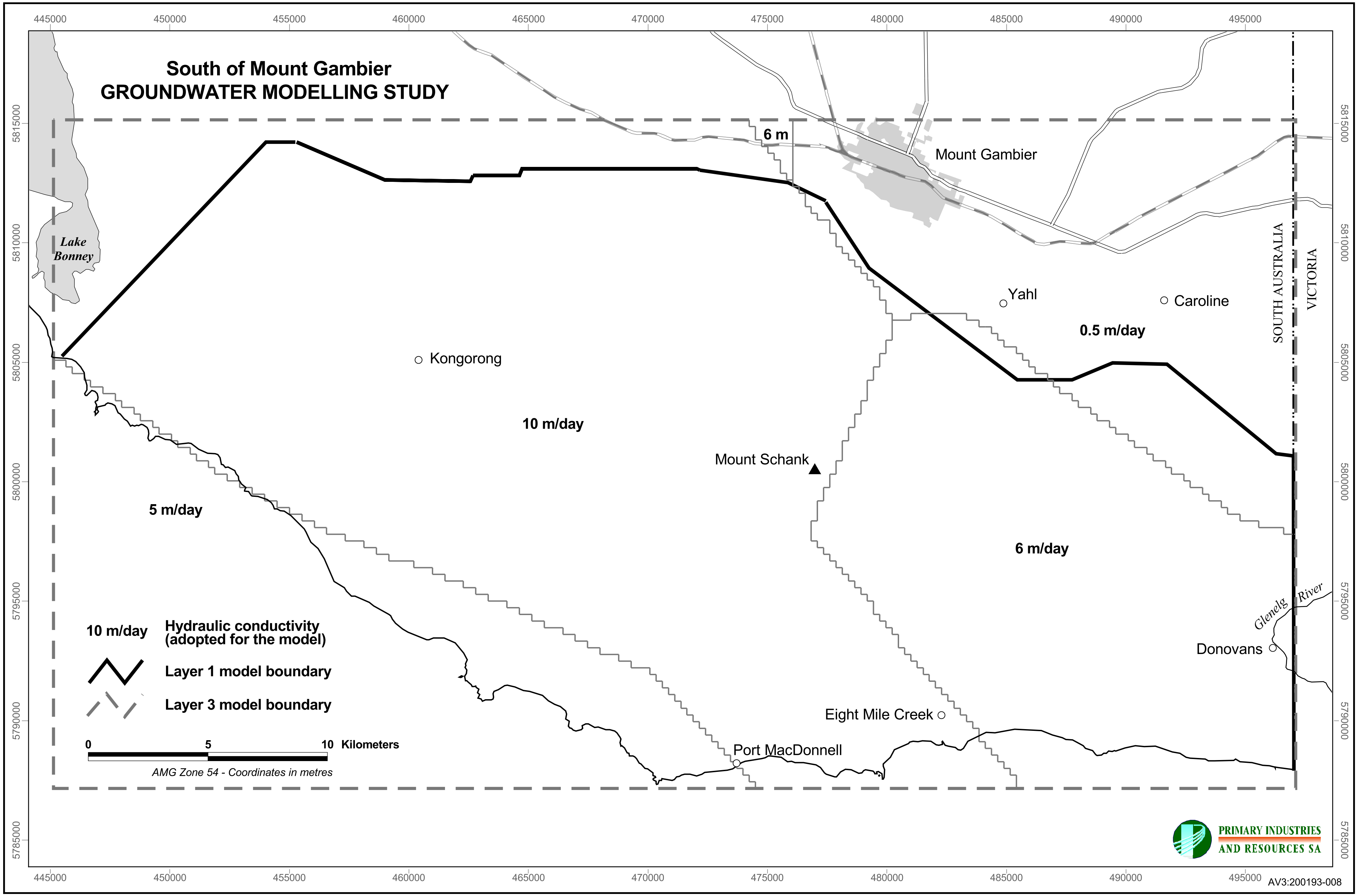


Figure 13 *Zones and hydraulic conductivities for the confined aquifer.*

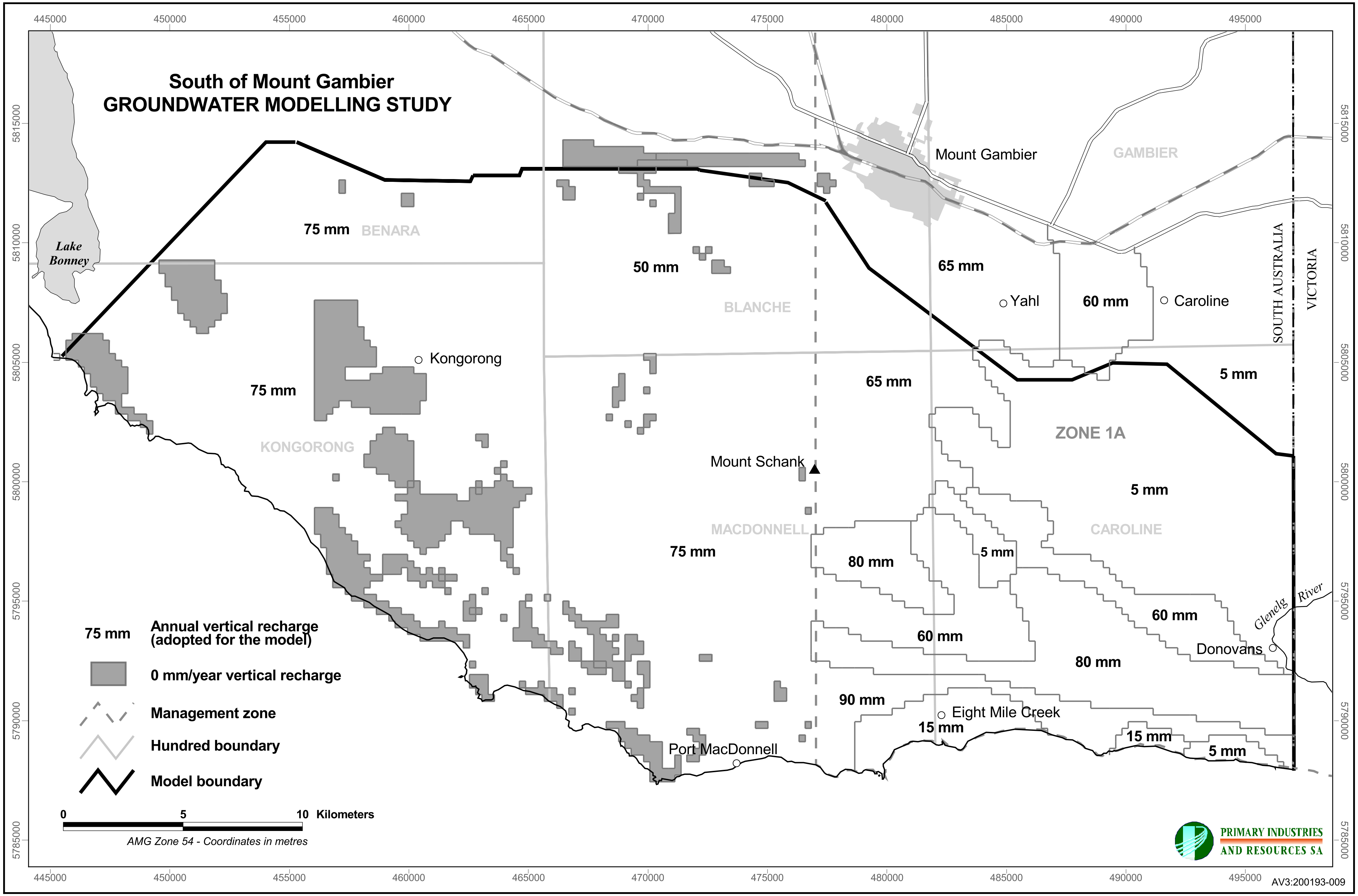


Figure 14 *Zones and rates of vertical recharge for the unconfined aquifer.*

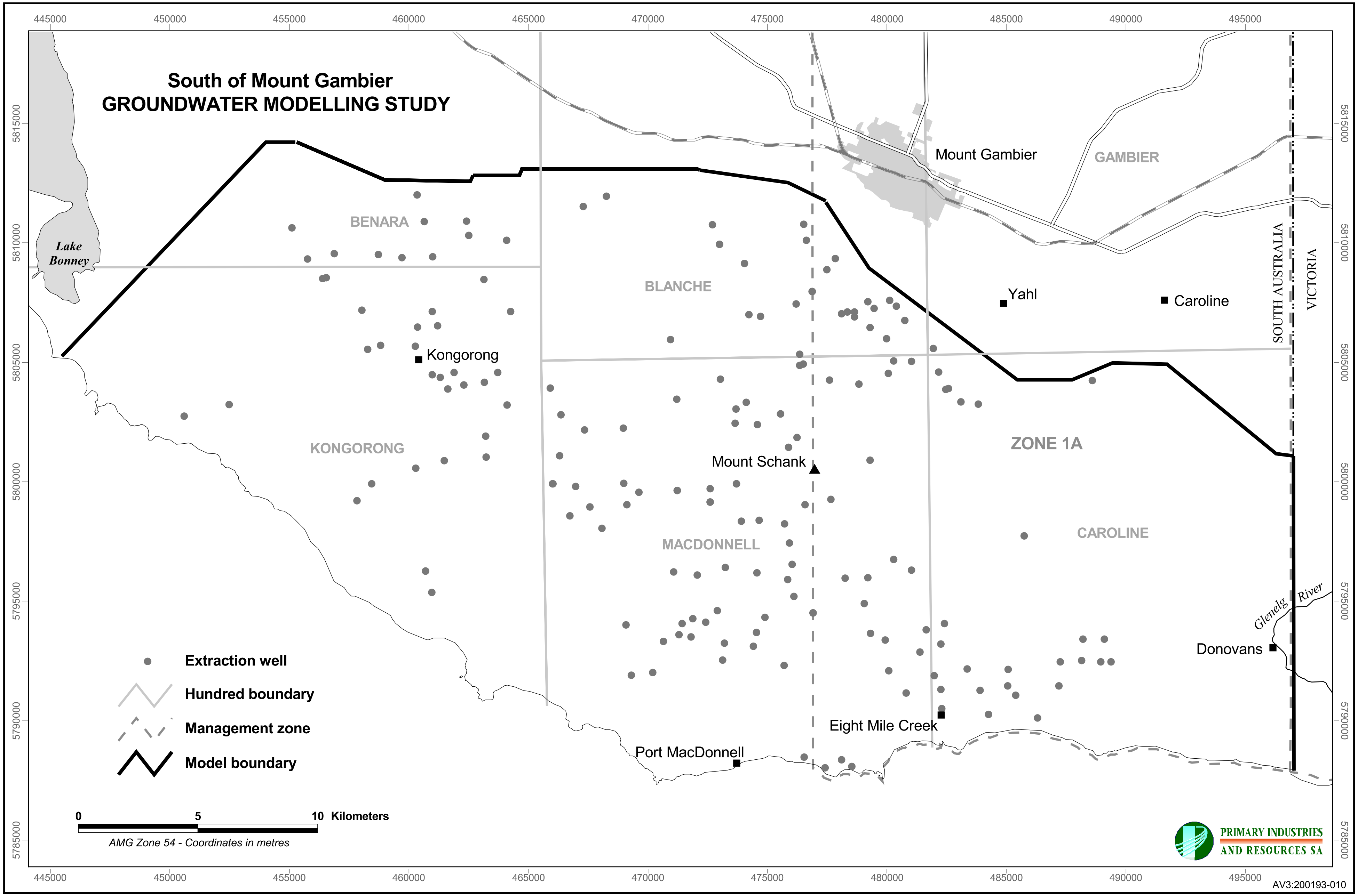


Figure 15 *Location of existing irrigation wells.*

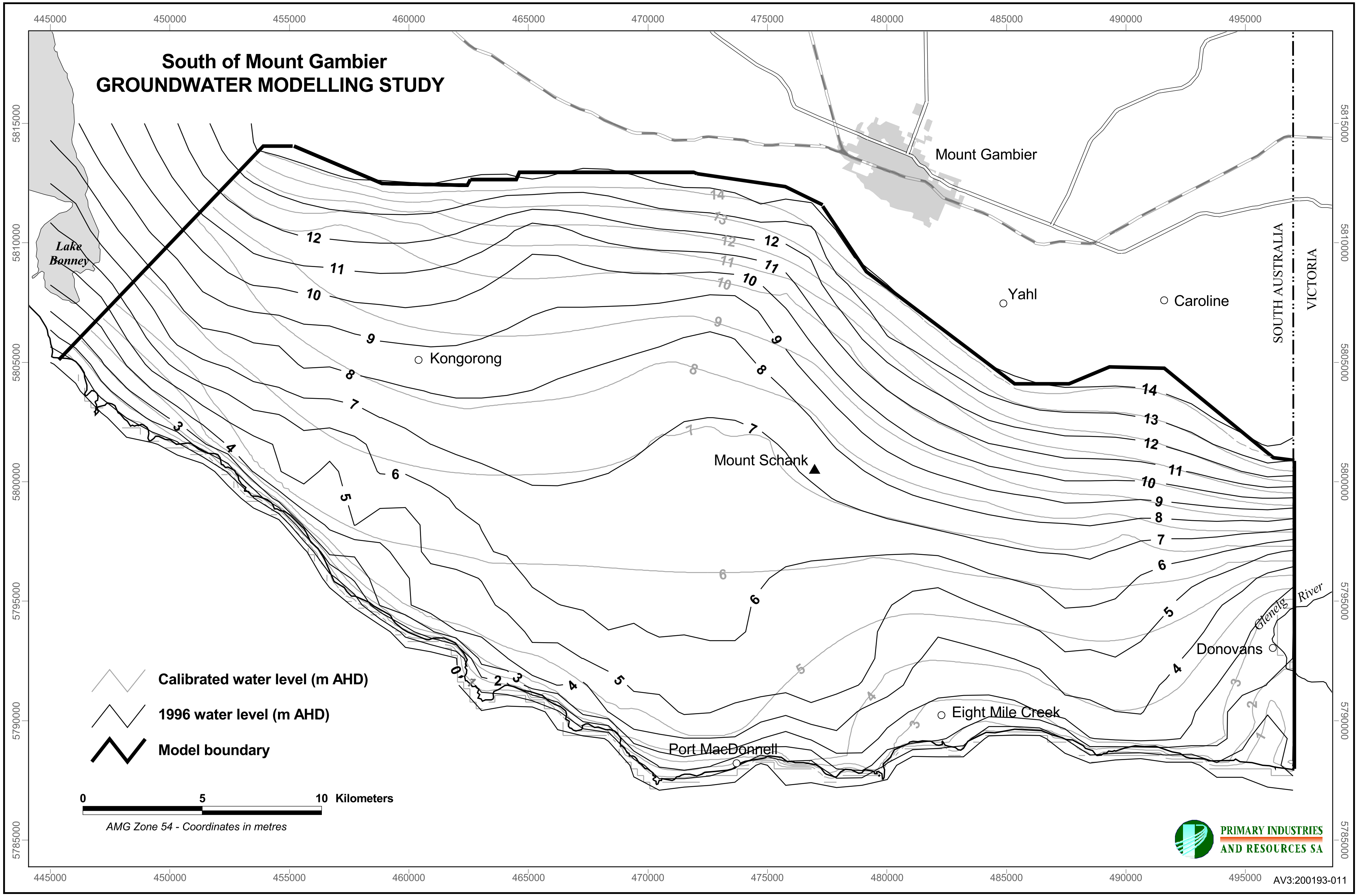


Figure 16 Comparison of calibrated and observed 1996 water level contours for the unconfined aquifer.

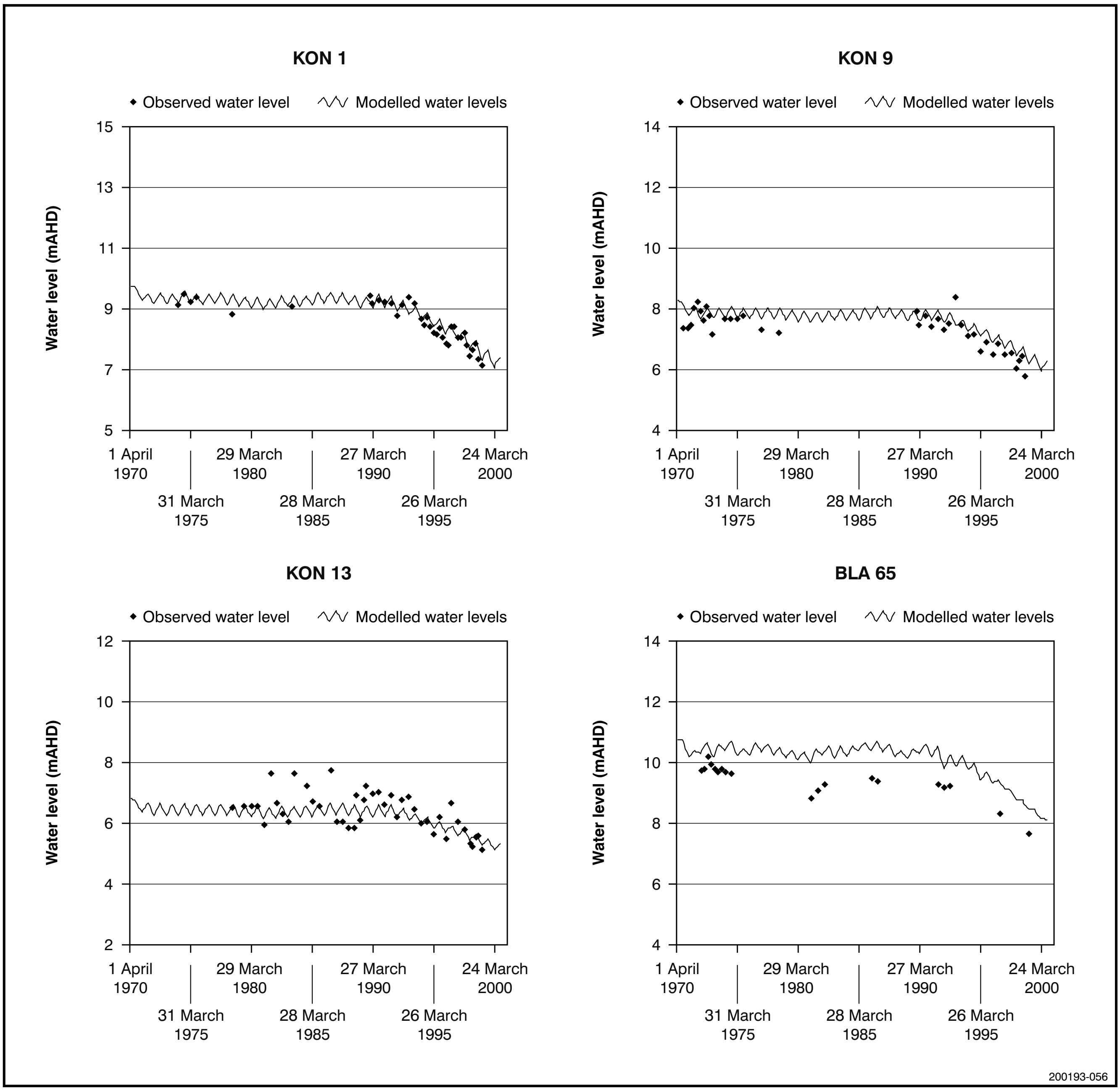


Figure 17 *Calibrated and actual water levels for observation wells KON 1, KON 9, KON 13 and BLA 65.*

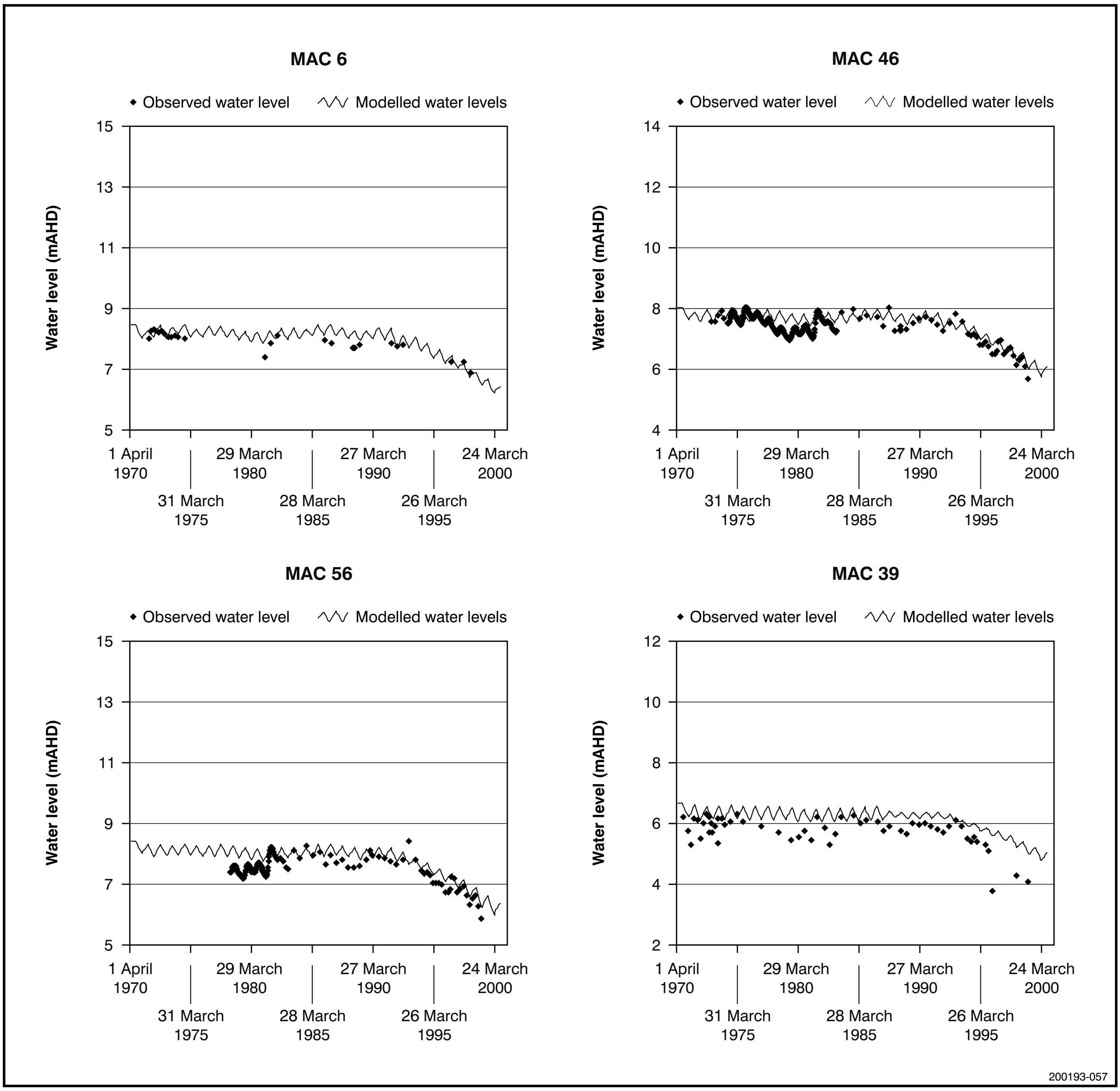


***Figure 18** Calibrated and actual water levels for observation wells MAC 6, MAC 46, MAC 56 and MAC 39*

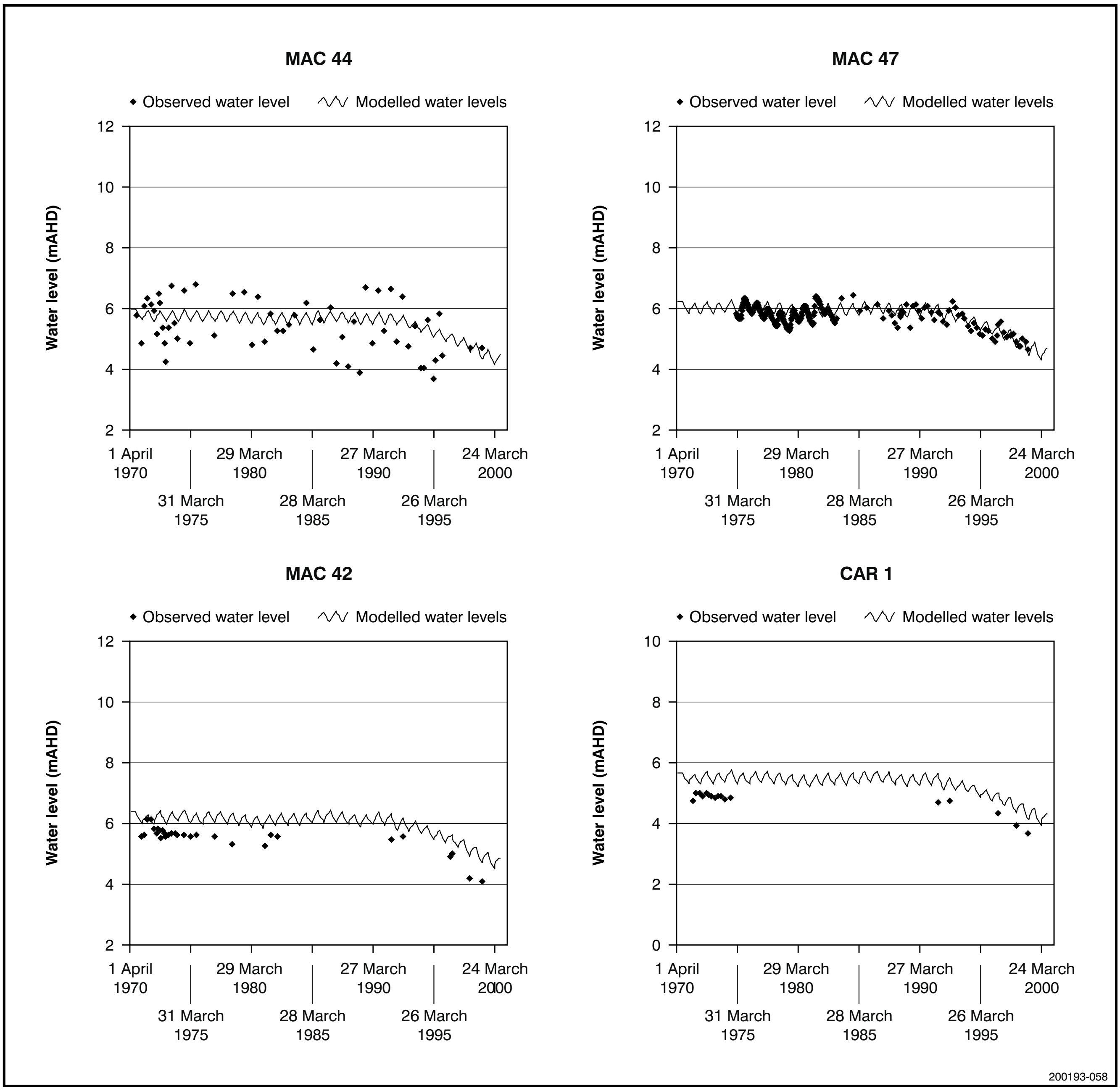


Figure 19 Calibrated and actual water levels for observation wells MAC 44, MAC 47, MAC 42 and CAR 1.

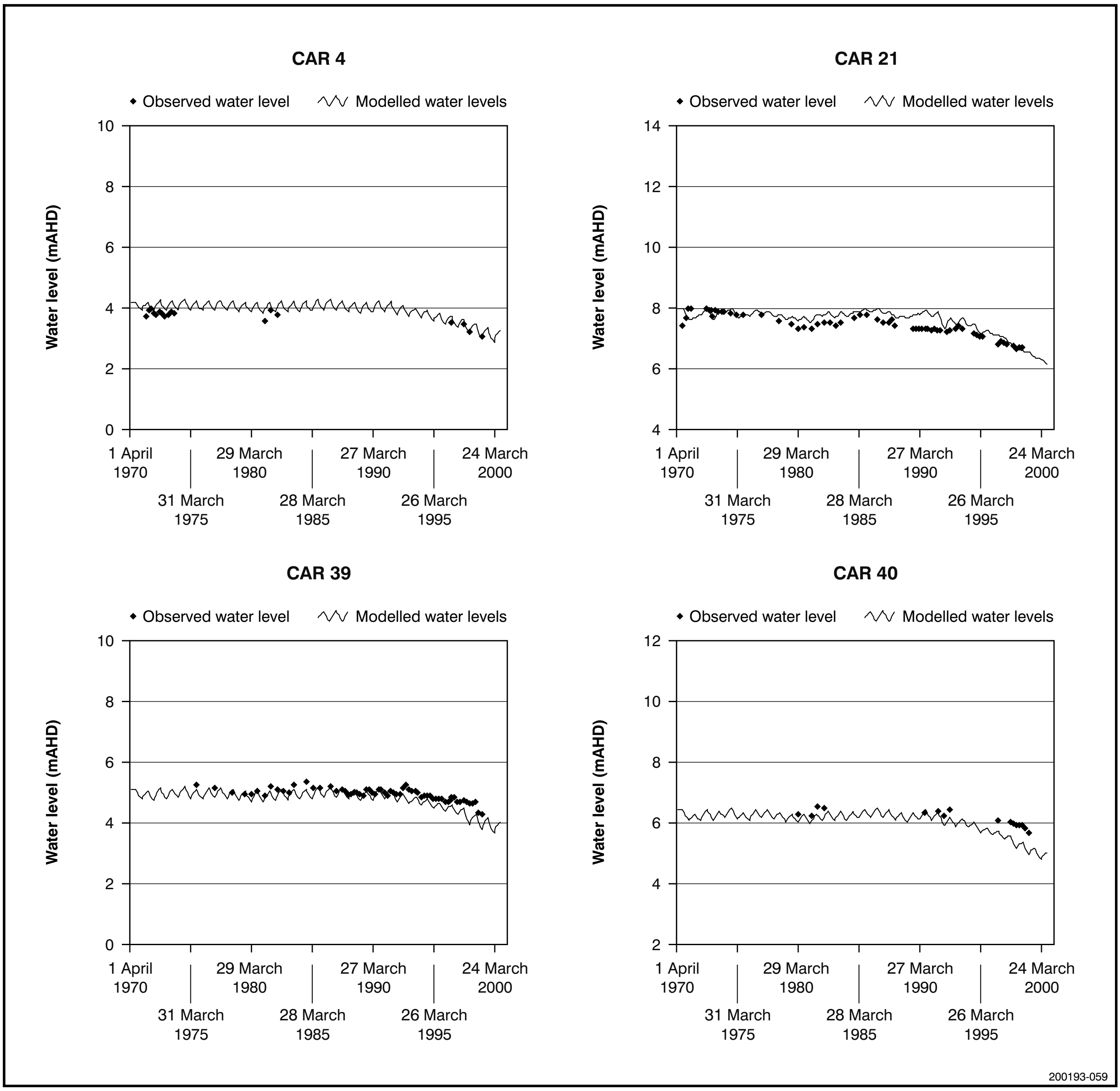


Figure 20 *Calibrated and actual water levels for observation wells CAR 4, CAR 21, CAR 39 and CAR 40.*

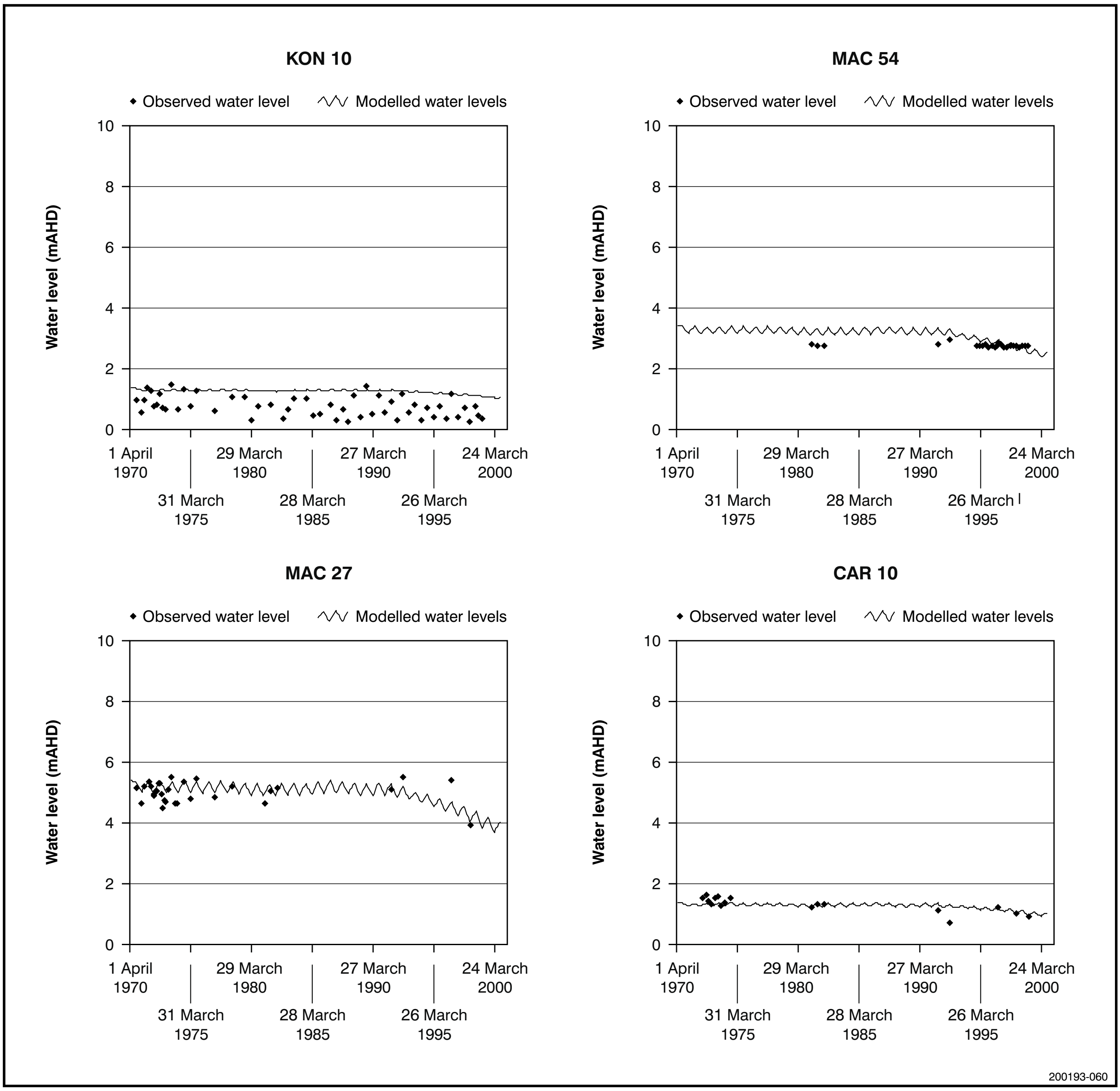


Figure 21 *Calibrated and actual water levels for observation wells KON 10, MAC 54, MAC 27 and CAR 10.*

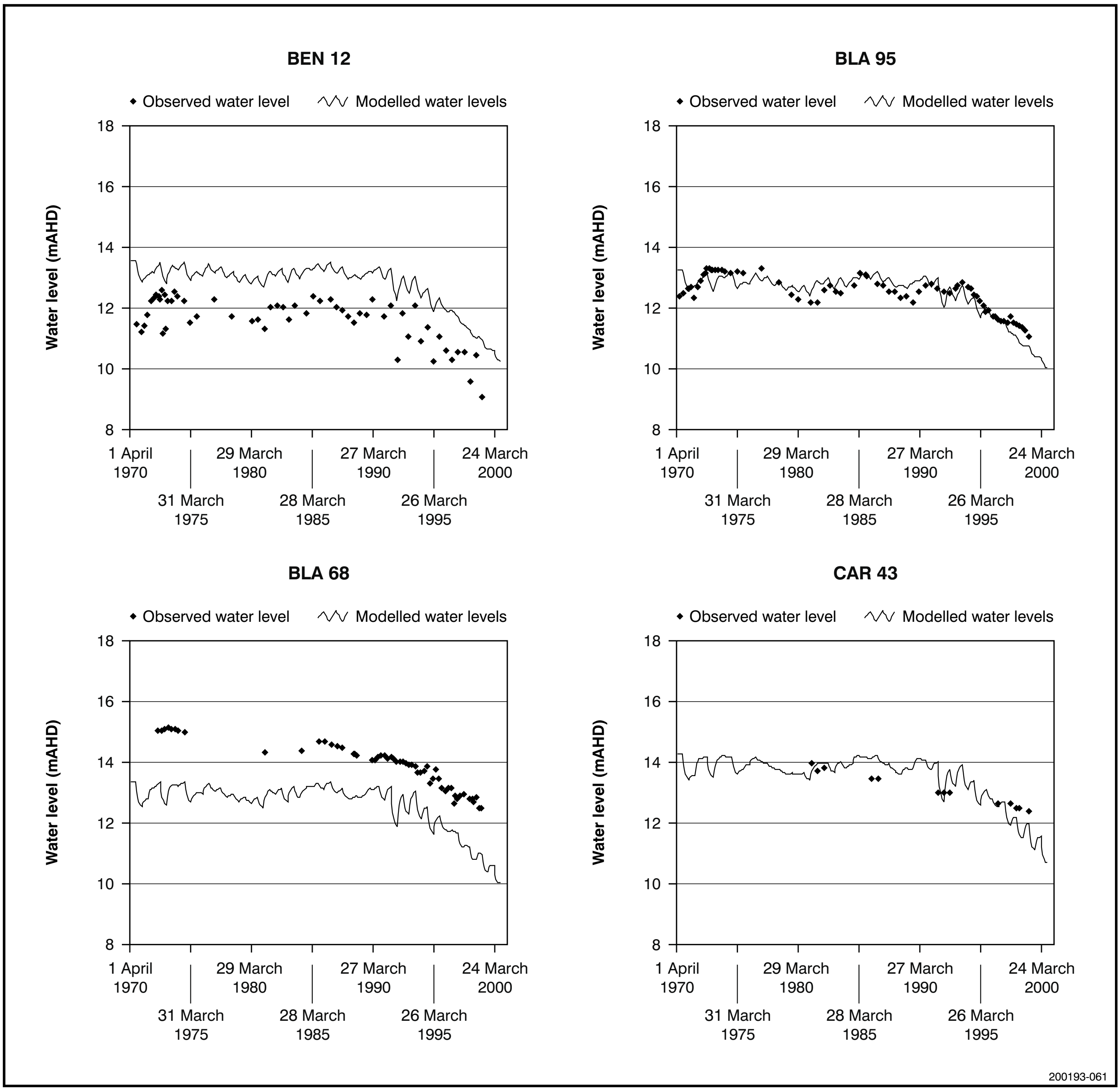


Figure 22 *Calibrated and actual water levels for observation wells BEN 12, BLA 95, BLA 68 and CAR 43.*

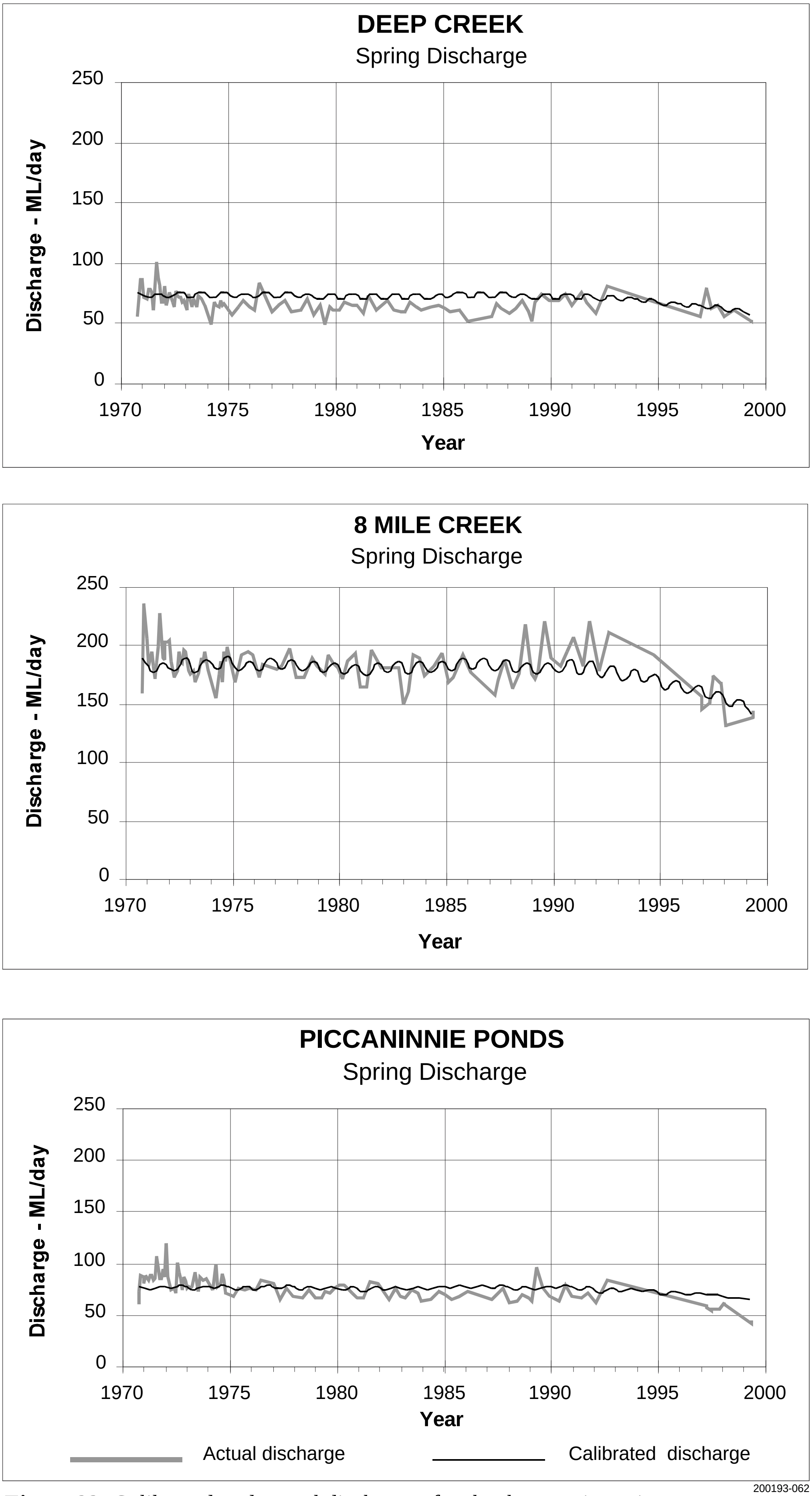


Figure 23 *Calibrated and actual discharges for the three main springs*

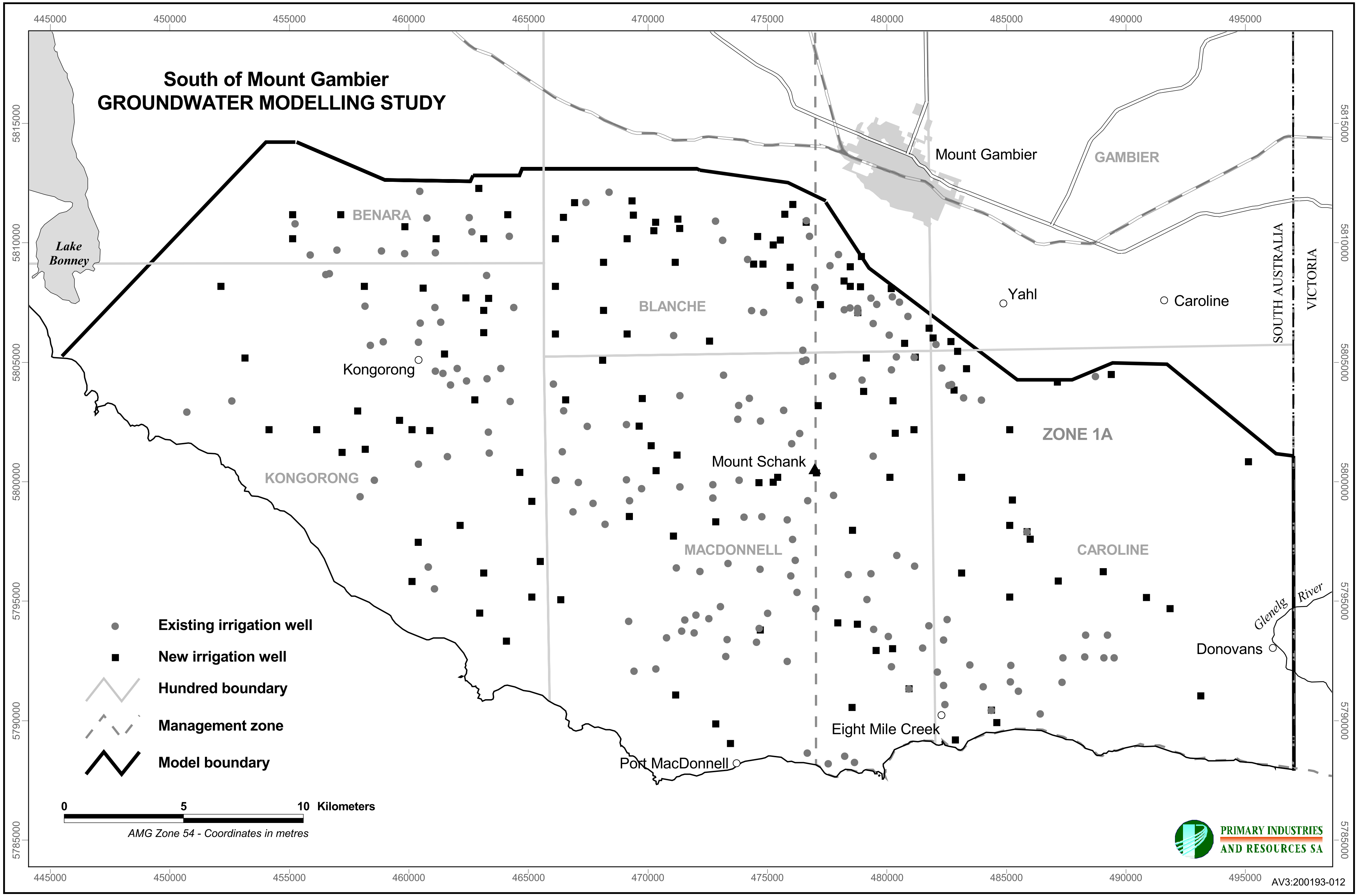


Figure 24 *Location of existing and new irrigation wells used for the model scenarios.*

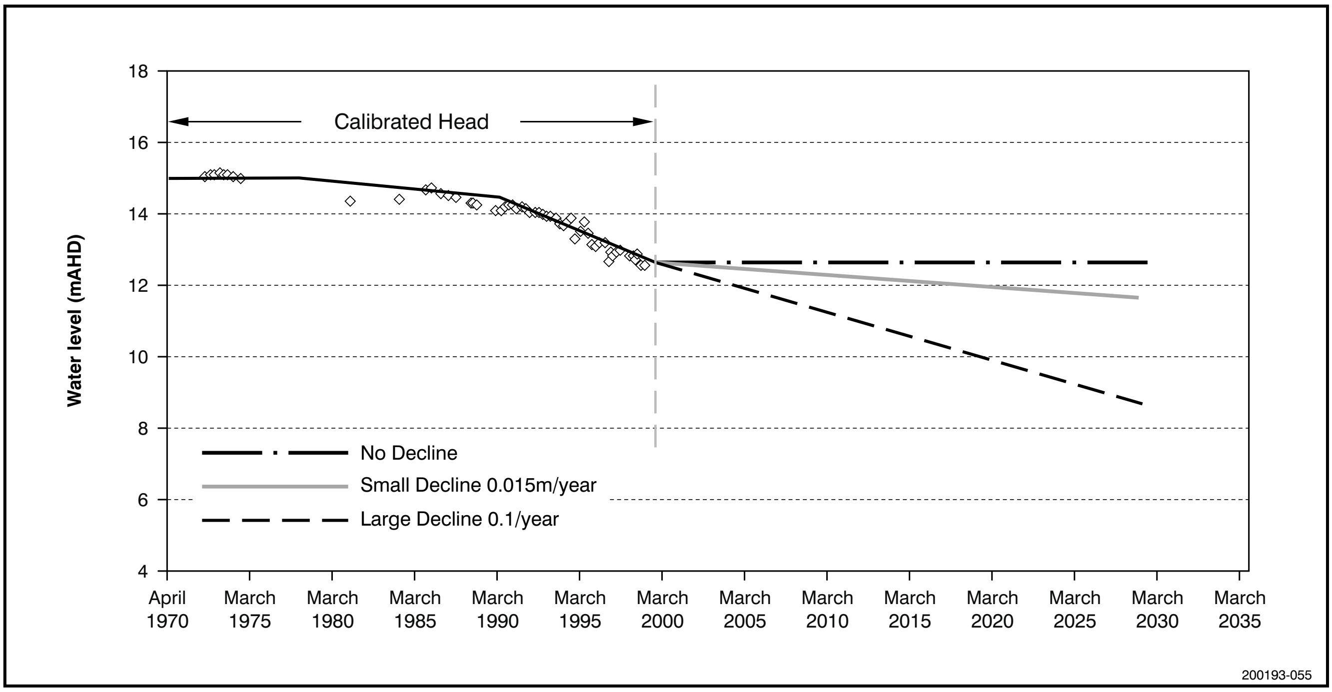


Figure 25 *Three different northern head conditions for Layer 1.*

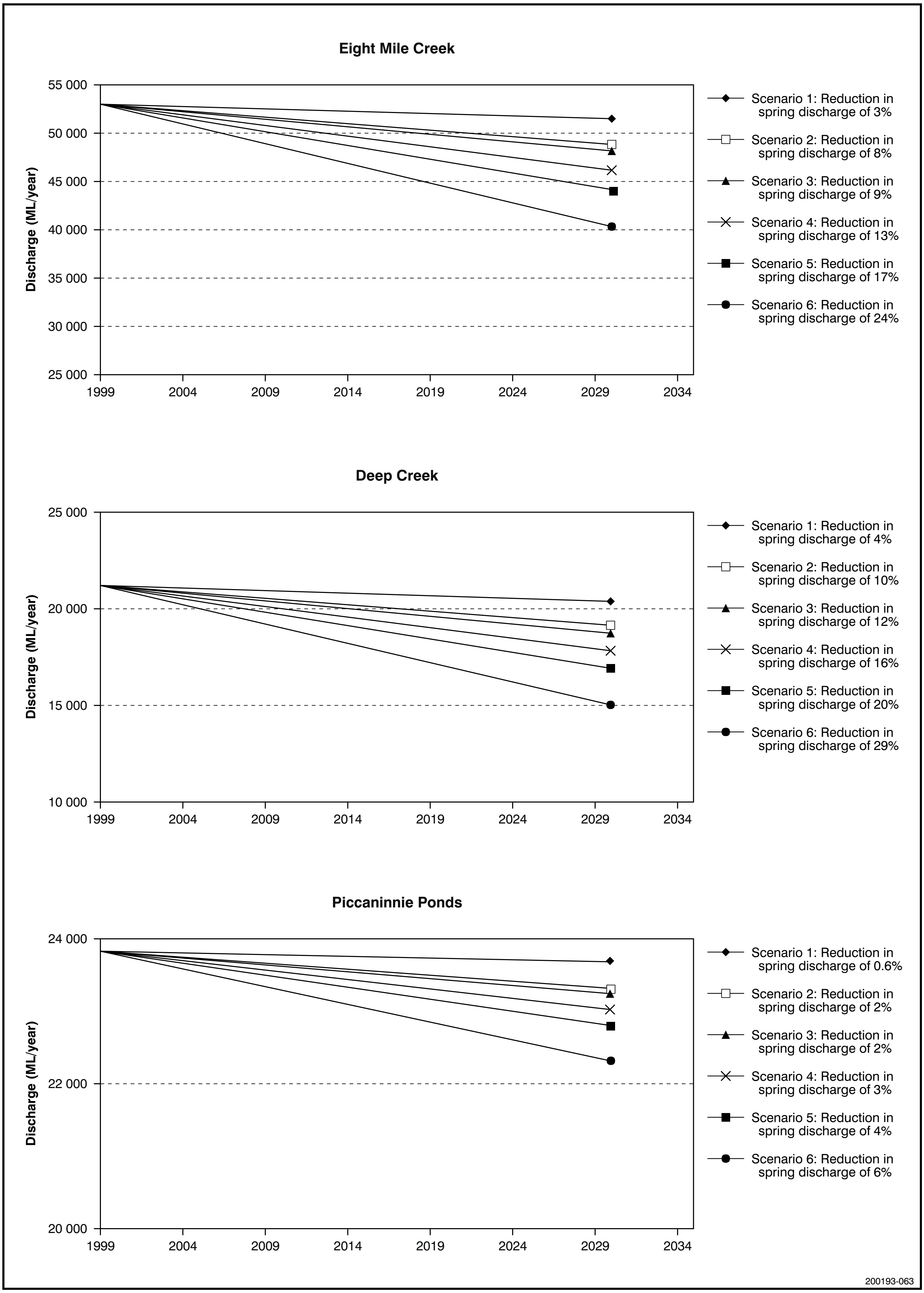


Figure 26 Predicted changes in spring discharges for different model scenarios with no head change on northern boundary.

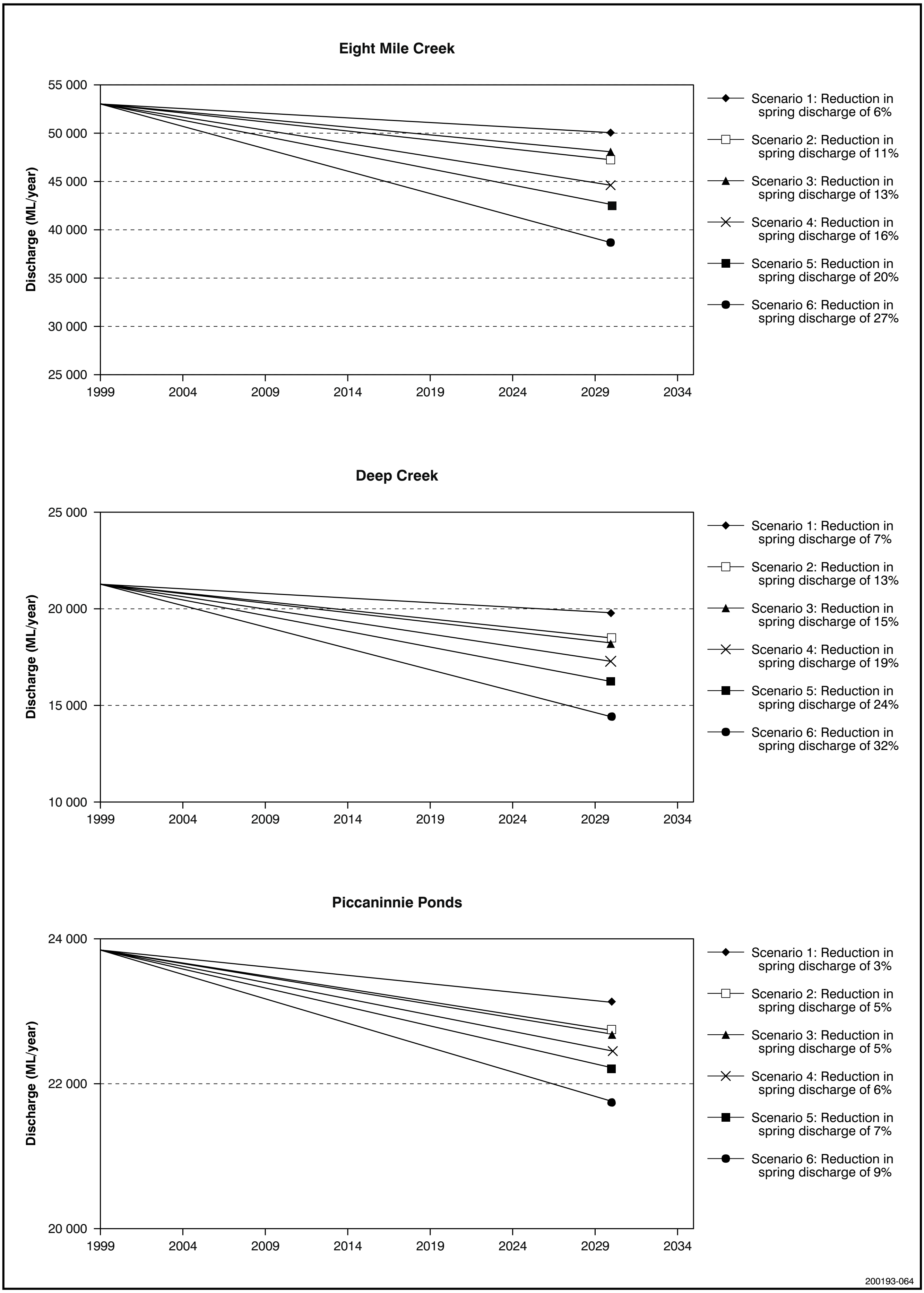


Figure 27 *Predicted changes in spring discharges for different model scenarios with a small head decline on northern boundary.*

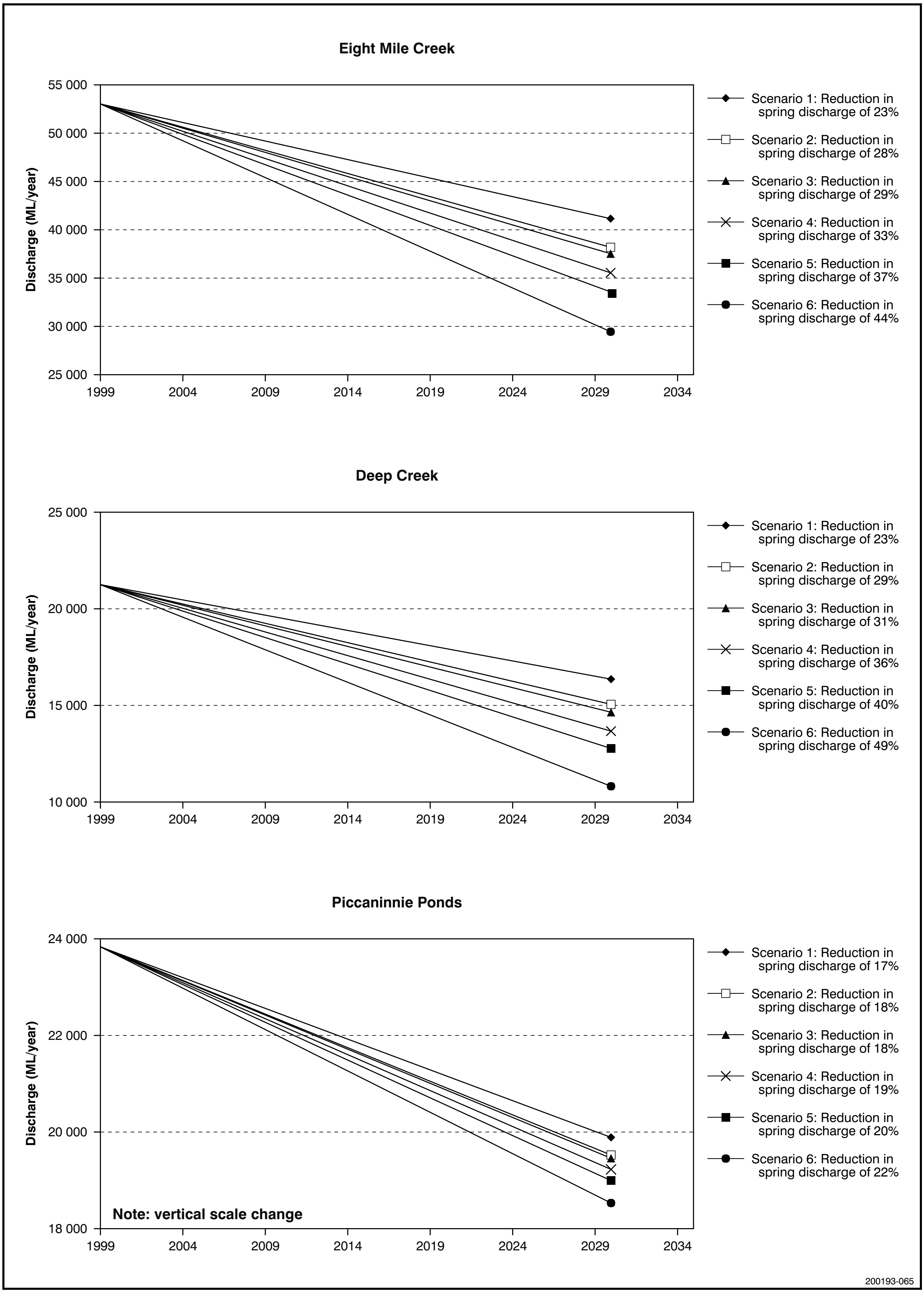


Figure 28 *Predicted changes in spring discharges for different model scenarios with a large head decline on northern boundary.*

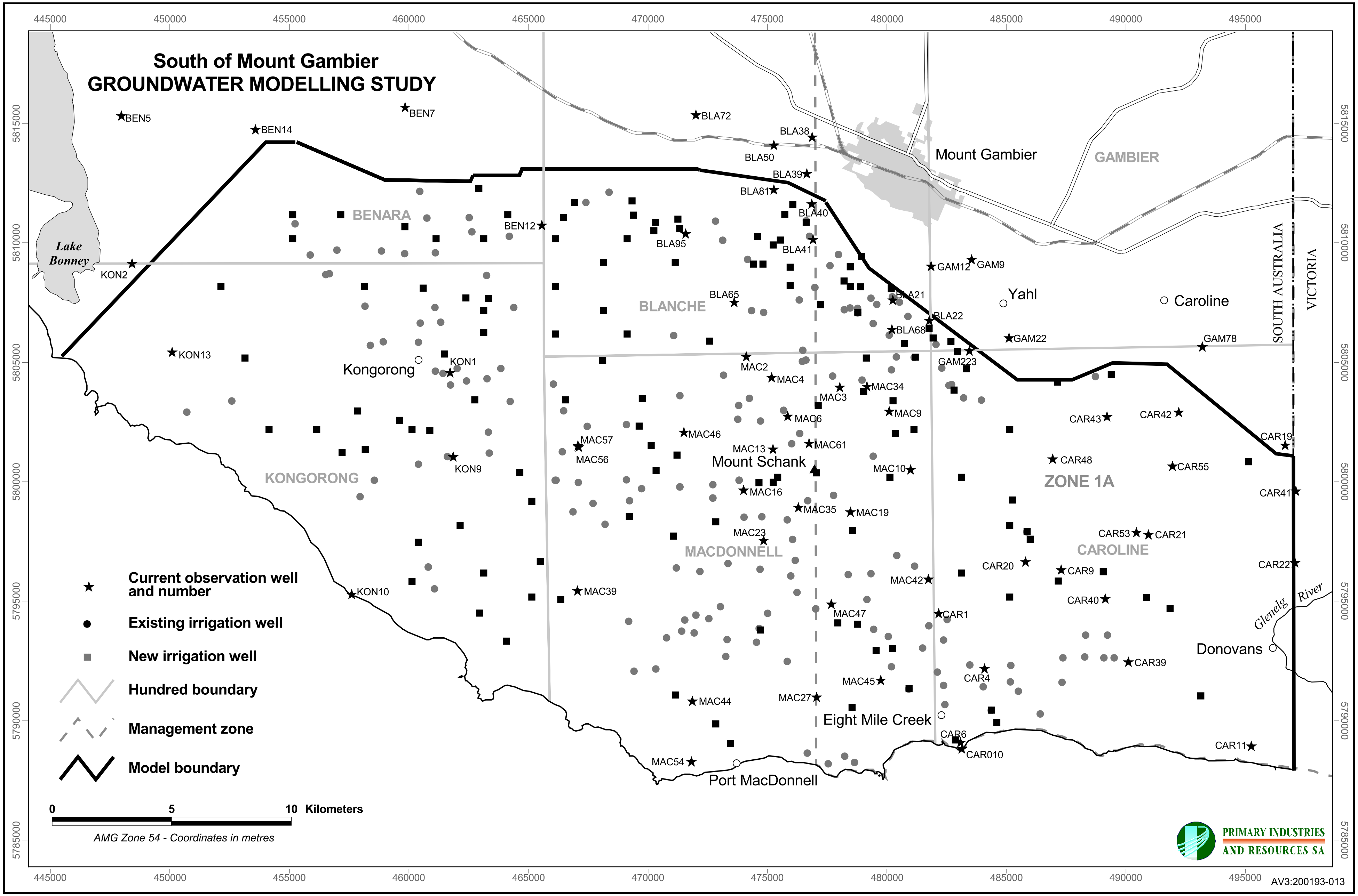


Figure 29 *Location of existing and new irrigation wells used for the model scenarios, and current observation wells.*